O

Object Permanence

Jeroen Zewald[1] and Ivo Jacobs[2]
[1]Animal Behaviour and Cognition, Utrecht University, Utrecht, The Netherlands
[2]Department of Cognitive Science, Lund University, Lund, Sweden

Definition

Object permanence is the capacity to represent objects as persisting in time and space independently of perception.

Introduction

Object permanence is one of the most studied abilities in animal cognition. In the early twentieth century, researchers investigated memory by hiding a food reward in one of several opaque containers and allowing the animal to retrieve it after a delay (e.g., Tinklepaugh 1928). This research on *delayed reactions* tacitly involved object permanence, which was not explicitly considered a separate cognitive capacity until the influential studies of Piaget (1954). He found that children develop object permanence in stages throughout early childhood. Behavioral biologists and comparative psychologists later used the Piagetian framework to document the cognitive development of various species. They discovered that not all species reach all six stages of object permanence as humans do while acknowledging that the Piagetian tasks are not suitable for many species and that numerous other factors affect performance. The debate on optimal methods continues. Recent research tries to disentangle these confounds and test animals in multiple carefully controlled conditions, with the overarching aim to describe why some species perform better than others in the light of their respective natural histories.

Piagetian Stages of Object Permanence

Piaget (1954) observed the development of his children through spontaneous behavior and informal experiments. He concluded that children, from birth to 2 years of age, progress through six stages of object permanence, with increasing cognitive demands (Table 1). In general, object permanence is tested by letting a subject search for a hidden object, which is often a toy for children and a food reward for animals. The ability to find these rewards under various conditions indicates how well the subject understands the concept of object permanence.

Stage 1: No Response to Objects

During Stage 1, subjects are not yet capable of recognizing and searching for objects (Piaget 1954). They do not show any visual or motor responses to a surrounding object or reward.

J. Vonk, T. K. Shackelford (eds.), *Encyclopedia of Animal Cognition and Behavior*,
https://doi.org/10.1007/978-3-319-47829-6_2103-1

Since this is the first stage that subjects possess from birth, the criteria for this stage is that Stage 2 of object permanence has not been reached yet. Precocial animals such as chickens are more active and independent from their first day and start life at a higher stage of object permanence (Doré and Dumas 1987).

Stage 2: Visually Tracking Objects

During Stage 2, subjects still do not actively search for a disappeared object. However, they do visually track the object or reward when it is moved in their visual field (Doré and Dumas 1987; Ujfalussy et al. 2013; Zucca et al. 2007). To test this stage, subjects are presented with an object that moves through a 180° arc. The passing criterion is that the subject visually pursues the moving object (with the eye, head, or full body movements).

Stage 3: Retrieving Partially Hidden Objects

During Stage 3, subjects can retrieve a partially hidden object (Doré and Dumas 1987; Singer and Henderson 2015; Ujfalussy et al. 2013). These tests are often done by covering half of a toy or food reward with a piece of cloth (e.g., Collier-Baker et al. 2004; Pepperberg et al. 1997; Piaget 1954; Zucca et al. 2007). The passing criterion is that the subject retrieves the partially hidden reward.

Stage 4: Retrieving Fully Hidden Objects

Understanding the permanence of object entails recognizing the persistence of objects independently of perception. Unlike earlier stages, Stage 4 involves tests with fully hidden objects. Typically, the reward is fully covered by one of several opaque *occluders*, and the subject is then allowed to search for it (Jaakkola et al. 2010; Piaget 1954). The occluder is usually a piece of cloth, box, cup, or screen. When presented with two occluders, of which only one is baited, subjects with object permanence are expected to select the baited occluder after observing the baiting procedure. This test is usually repeated multiple times with the same subject, such that performance is reflected in a score of X trials correct out of Y trials in total, which can be statistically compared to chance level (e.g., 50% correct when two occluders are used).

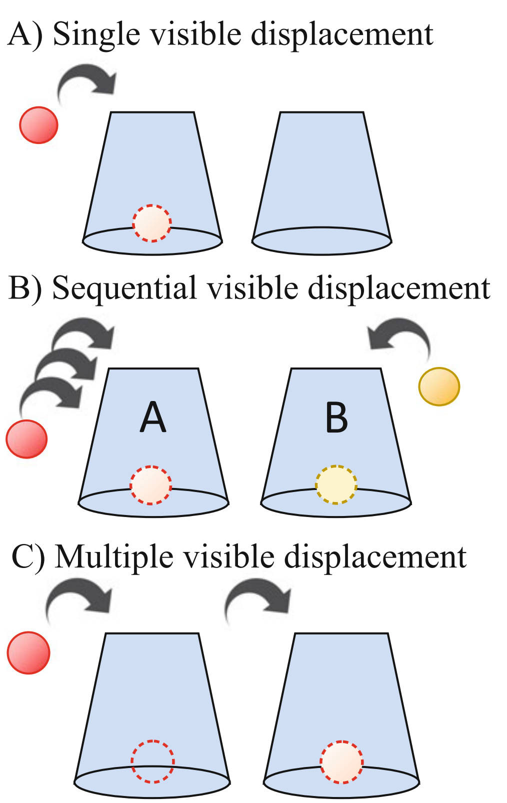
Two substages are recognized. In Stage 4a, a subject is able to choose correctly but only if it initiated its movement toward that occluder before the reward fully disappeared. In Stage 4b, the subject can select the correct occluder without such initial movement (Doré and Dumas 1987; Singer 2018; Ujfalussy et al. 2013). If the reward is moved from one location to the occluder during the procedure, this is called a *single visible displacement* (Fig. 1a). Delayed response tasks in which a reward is hidden behind an occluder, instead of an arbitrary cue such as a light, involve visible displacement. Performance differs strongly among primates, but overall, they always perform better when the delay between disappearance and search is shorter (Many Primates et al. 2019). The alternative method of placing occluders over the reward does not constitute displacement because the reward remains stationary.

Piaget noticed a strange error occurring in infants of 8–12 months old. After correctly retrieving the reward at location A over several trials, subjects kept searching at location A in subsequent trials even after seeing the reward was now hidden at location B. This is called the *A-not-B error* or the *perseveration error*. Animals often make the same error (Cacchione and Rakoczy 2017; Doré and Dumas 1987; Osthaus 2017; Piaget 1954; Ujfalussy et al. 2013). Individually, these subsequent trials are still single visible displacements, but to distinguish them as a group, this procedure is called *sequential visible displacement* (Fig. 1b).

The A-not-B error becomes more prevalent with a larger number of preceding A trials, an increased delay between hiding and retrieval, more complex motor requirements for retrieval, and generally if the subject is younger. This pattern suggests that the error arises from overburdened executive functions, which develop with age (Cacchione and Rakoczy 2017; Osthaus 2017). Importantly, a subject may accurately appreciate object permanence but still commit the A-not-B error because it fails to attend to the sequence, inhibit previously learned responses,

Object Permanence, Table 1 Summary of the Piaget stages in object permanence. (Adapted from De Blois et al. (1998))

Stages	Description
1	No response to the object
2	Visually tracking the object
3	Retrieving partially occluded objects
4a	Retrieving fully occluded objects with initiated motion
4b	Understanding single visible displacement (with A-not-B error)
5a	Understanding single visible displacement (no A-not-B error)
5b	Understanding multiple visible displacements
Simple object permanence	
6a	Understanding single invisible displacements
6b	Understanding multiple invisible displacements
Full object permanence	



Object Permanence, Fig. 1 **Visible displacements.** The most common visible displacement tasks. (**a**) The object is placed under an occluder. (**b**) The object is placed under occluder A in several trials followed by a trial where it is hidden under occluder B (as a test for the A-not-B error). (**c**) The object is first hidden under one occluder and then under the other occluder in the same trial. Dark objects are visible for the subject, transparent dots are intermediate positions, and light objects are in the final position

remember the correct location, or perform the required actions. Methodological developments aim to reduce the impact of these confounding factors (see section "Violation of Expectation Studies").

Stage 5: Understanding of Multiple Visible Displacements

Stage 5 also consists of two substages. In Stage 5a, subjects successfully search the correct location in the sequential visible displacement task without making A-not-B errors. In Stage 5b, subjects perform above-chance level in a *multiple (or successive) visible displacement task* (Cacchione and Rakoczy 2017; Doré and Dumas 1987; Ujfalussy et al. 2013). Here, the reward is hidden multiple times in the same trial (Fig. 1c). Typically, the experimenter holds the reward, shows it to the subject, moves it behind occluder A, removes it, and finally places it behind occluder B. The subject should then understand that the reward is no longer at location A but at location B. A common error is searching in the first place of disappearance, resulting in below-chance performance. Animals generally perform worse on multiple compared to single visible displacement tasks (Cacchione and Rakoczy 2017). Subjects have the ability of *simple object permanence* when they passed tasks of both substages.

Stage 6: Understanding of Invisible Displacements

In all earlier stages, the reward is always displaced in sight of the subject. In contrast, Stage 6 is tested by an *invisible displacement*; the reward is occluded during movement, and the subject has to track or infer its location (Doré and Dumas 1987; Piaget 1954; Singer and Henderson 2015; Singer 2018; Ujfalussy et al. 2013). Invisible displacements can be tested with the standard Piagetian task, the transposition task, or the rotation task.

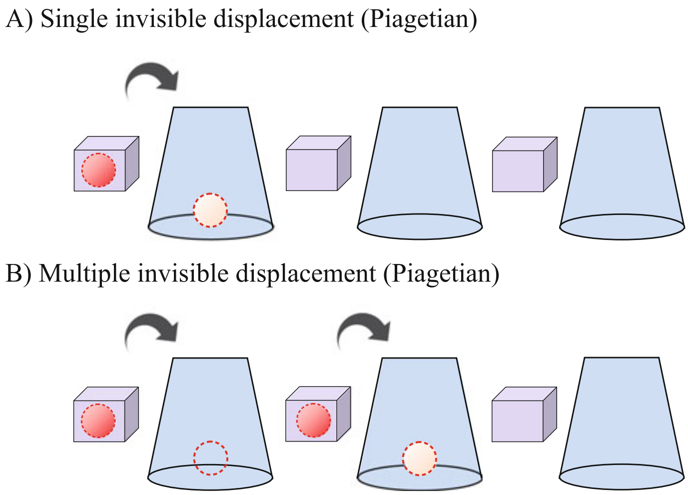
Standard Piagetian Task

The standard Piagetian task has been tested most often (Jaakkola 2014). It resembles the visible displacement tasks of Stage 5 except that the reward is hidden during movements and its location has to be inferred. In Stage 6a, the subject is presented with a *single invisible displacement*, in which the reward is moved only once per trial (Fig. 2a). In Stage 6b, the subject can successfully retrieve the reward in a *multiple invisible displacement* task when the reward is invisibly displaced multiple times during the course of a single trial (Fig. 2b). In general, multiple occluders and an opaque *displacement device* are used. This displacement device holds the reward during movement (Cacchione and Rakoczy 2017; Jaakkola et al. 2010; Piaget 1954; Singer 2018). Often, a small container or the experimenter's hand is used as a displacement device, as both can cover the reward and move it between locations. Tasks for both substages start by the experimenter visibly placing the reward in the opaque displacement device, after which the subject can no longer see the reward. The displacement device is then moved behind or under the first occluder. In tests for Stage 6a, the reward is deposited there, and the subject is shown that the displacement device is now empty. In tests for Stage 6b, the reward is either similarly deposited behind the occluder or kept in the displacement device to be moved to the next occluder(s). The subject is then allowed to search for the reward. By tracking and inferring the position of the reward, the subject should search the occluder after which the displacement device was shown empty and thus where the reward has been left behind. Subjects that passed tasks of both substages are said to have *full object permanence*.

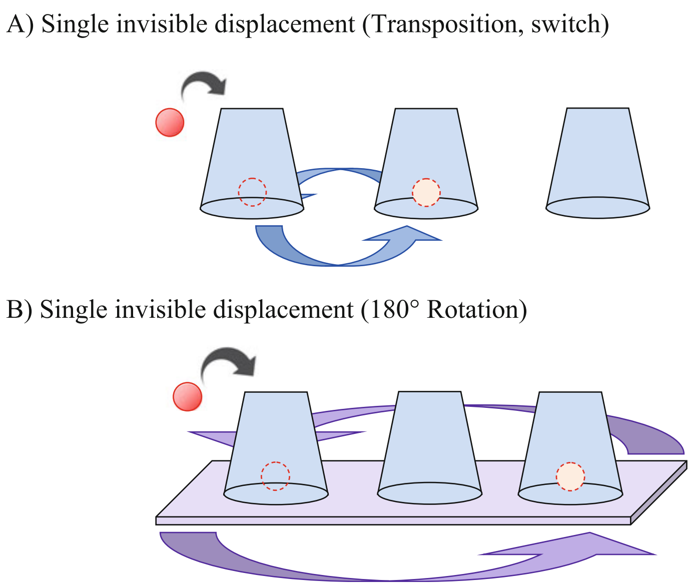
This task has at least five key requirements: (1) understanding that the reward continues to exist after disappearance (simple object permanence), (2) inferring that the reward moves with the displacement device, (3) inferring that the reward has been left behind after the displacement device is shown to be empty, (4) updating the location of the reward during its movements, and (5) inhibiting prepotent responses (Cacchione and Rakoczy 2017). The third requirement is called reasoning by exclusion, which entails representing multiple alternatives ("A or B") and then ruling out one alternative ("not A"), leading to the conclusion that the remaining alternative must be true ("therefore B"). Many animals that have simple object permanence struggle with such tasks (Klerk and Jacobs 2021). Thus, the standard Piagetian invisible displacement is much more cognitively demanding than a visible displacement (Jaakkola et al. 2010).

Transposition Task

No displacement device is needed in the transposition task. The experimenter visibly hides the reward under an occluder and then moves the occluder(s) around (Fig. 3a). The subject can choose the correct occluder by tracking the invisibly displaced reward. There are four typical sequences in which the occluders are moved, with increasing cognitive demands (Cacchione and Rakoczy 2017; Jaakkola 2014; Majecka and Pietraszewski 2018; Singer 2018). The first is a *simple lateral* movement, where the occluders move laterally to a new location and the original location of the baited occluder remains empty (Fig. 4a). The second is a *lateral substitution*, where the occluders also move laterally and an empty occluder takes the original position of the baited occluder (Fig. 4b). The third is a *simple cross*, where the occluders cross during their movements and the original location of the baited occluder remains empty (Fig. 4c). The fourth movement is a *switch* or *shell game*, where the occluders also cross during their movements but



Object Permanence, Fig. 2 Standard Piagetian invisible displacements. The two substages in invisible displacement tasks. (**a**) The object is hidden in the displacement device and then transferred to one occluder. After that, the displacement device is shown to be empty. (**b**) The object is hidden in the displacement device and then transferred to one occluder. After that, the object is transferred with the displacement device and shown to the subject after which it is hidden at another occluder. Dark objects are visible for the subject, transparent dots are intermediate positions, and light objects indicate the final position

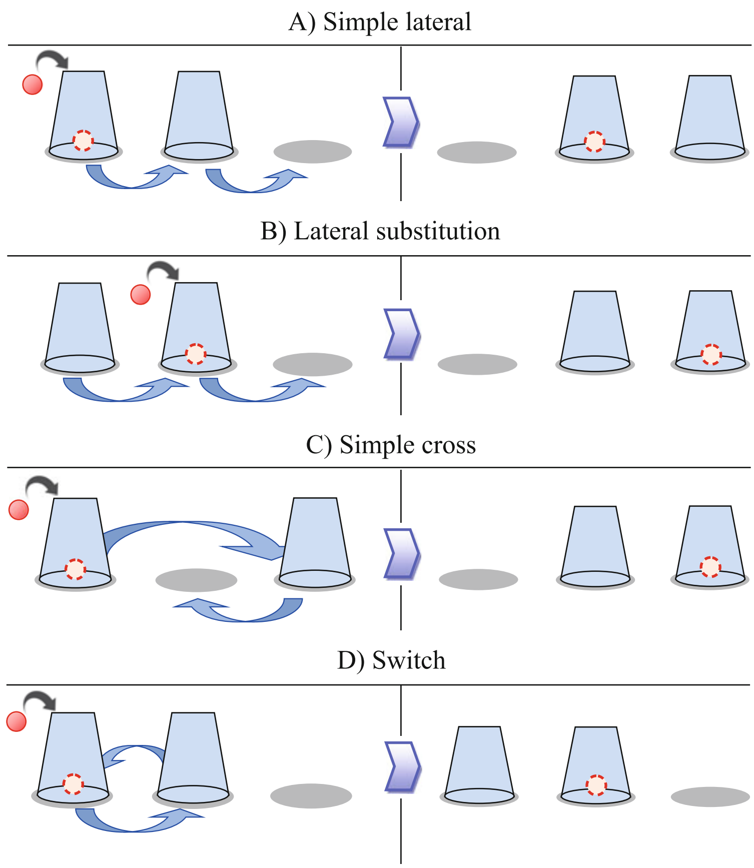


Object Permanence, Fig. 3 Invisible displacement: transposition and rotation. The two alternatives to the standard Piagetian invisible displacement task. (**a**) After hiding the object under an occluder, two occluders switch positions. (**b**) After hiding the object under an occluder, the whole tray is rotated (180°). Dark objects are visible for the subject, transparent dots are intermediate positions, and light objects are in the final position

an empty occluder is moved to the original location of the baited occluder (Fig. 4d).

Rotation Task

All variations of the rotation task involve multiple occluders that are closed on all sides (e.g., cups or boxes) and do not use a displacement device. The occluders are placed on a flat platform that can easily be rotated. One occluder is visibly baited with the reward. Instead of moving the occluders individually as in transposition tasks, the whole platform is turned (Fig. 3b). After it has been



Object Permanence, Fig. 4 The four types of transpositions. The initial setup with movements is presented in the left column, and the final situation is shown in the right column. (**a**) Simple lateral transposition, where the cups do not cross and the originally baited position remains empty. (**b**) Lateral substitution, where the cups do not cross and the originally baited position is taken by an empty cup. (**c**) Simple cross, where the cups cross each other and the originally baited location remains empty. (**d**) Switch, where the cups cross each other and the originally baited location is taken by an empty cup

turned, the subject is allowed to search the occluders for the reward. The most common rotations are 90°, 180°, and 360°. Animals generally perform better after a 90° rotation, where both occluders move to new positions, than a 180° rotation, where the occluders switch positions (Jaakkola 2014; Singer 2018). However, a methodical disadvantage of the 90° rotation task is that one of the occluders is behind another and is therefore less visible and accessible (Jaakkola 2014).

Task Comparisons

These different methods of invisible displacement appear to have different demands. The standard Piagetian task is challenging as it involves complex nested movements with invisible transfer of the reward, and it requires inference that the reward was removed after observing the empty displacement device. Transposition and rotation tasks do not have this nested invisible transfer, but they involve more moving occluders. The sequential movements of transposition tasks may be easier to attend to than the simultaneous movements of rotations (Cacchione and Rakoczy 2017; Jaakkola 2014). Thus, the tasks differ along multiple dimensions that may have divergent effects on different species. Moreover, each task may be passed by using different cues and heuristics, which are discussed further below (see section "Methodical Issues and Improvements"). Children – but not great apes – perform better in the standard Piagetian task than the switch version of the transposition task. The 180° rotation task was found to be most difficult by both apes and children (Barth and Call 2006; Jaakkola 2014). Species comparisons on transposition tasks show that apes perform better than monkeys, which in turn outperform dogs, and that cross and switch conditions are overall most challenging (Majecka and Pietraszewski 2018).

Development of Object Permanence

Piaget formulated the stages of object permanence as a developmental sequence in children. Uzgiris and Hunt (1975) further developed these methods with a clearer scoring system and split the different stages in 15 tasks. Each subject was repeatedly tested on a task and proceeded to the next task when successful in the majority of trials. As a result, these tasks were ordered by cognitive demands based on performance (Jaakkola 2014; Uzgiris and Hunt 1975).

Animals have been tested in similar developmental studies (Doré and Dumas 1987; Pepperberg et al. 1997). The focus lies less on when a species passes a certain stage, which is not a particularly meaningful measure, and more on whether a certain stage is passed and in what order (Pepperberg 2002). Knowing the "final stage" of multiple species can be used to determine coupled abilities, ecological relevance, and evolutionary history. Studies have been done on many mammal and bird species (Barth and Call 2006; Collier-Baker et al. 2004; De Blois et al. 1998; Lambert et al. 2019; Pepperberg et al. 1997; Ujfalussy et al. 2013; Zucca et al. 2007). In general, adult great apes, parrots and corvids reach Stage 6 and perform better than their close relatives. Object permanence develops in a similar sequence across species, except that some species do not reach later stages and precocial species start life in a stage later than the first. Its developmental speed generally reflects the life history of the species, with faster developing species also reaching the final stage faster (Doré and Dumas 1987; Jaakkola 2014; Lambert et al. 2019; Pepperberg 2002).

Most studies focus on the visible and invisible displacement tasks and do not test the entire range of Uzgiris and Hunt's or Piaget's tasks (Cacchione and Rakoczy 2017). Thus, studies often neglect earlier stages, which complicates inferring the animals' motivation and ability to track and retrieve objects. An animal with full object permanence may seem to lack this ability when not showing sufficient attention and motivation during testing. Similarly, inability to retrieve objects and remove occluders in experimental conditions may give the false impression that object permanence is lacking (see section "Violation of Expectation Studies"). Thus, these aspects should be addressed to avoid false negatives – especially for younger animals in developmental studies. Future studies should therefore test visual tracking for monitoring attention and use transparent occluders to document motivation and ability to retrieve the reward when it remains visible.

Adaptive Significance

Although much research has focused on the maximal stage a species can reach, only little attention has gone to the potential adaptive significance of reaching a certain stage. Achieving the first stages, and doing so at an early age, is certainly crucial for various survival skills of visual animals. The later ability to represent temporarily unperceivable agents and objects also has clear benefits in many situations, such as foraging, predator avoidance, and social behavior. An animal sticking its head in the sand to evade predators like the proverbial ostrich would not be long for this world. Nonetheless, empirical studies on the adaptive significance of object permanence are scarce, and explanations for its phylogenetic spread are speculative. Visible and invisible displacement have been discussed most in this context.

Visible Displacement

Understanding visible displacements is an ability reached by species of many taxa, such as great apes, monkeys, dogs, cats, parrots, pigeons, chickens, corvids, and fish (e.g., Cacchione and Rakoczy 2017; Collier-Baker et al. 2006; Fiset and LeBlanc 2007; Jaakkola et al. 2010; Jaakkola 2014; Majecka and Pietraszewski 2018; Singer and Henderson 2015; Sovrano et al. 2018; Ujfalussy et al. 2013; Zucca et al. 2007). Simple object permanence thus seems common – if not universal – across mammals and birds, and a wider phylogenetic spread would not be surprising given its benefits. Moving prey visibly displaces themselves to an observing predator, which will hunt more efficiently when attending to this movement and correctly locating the prey in the new hidden location, such as behind a tree or in a burrow (e.g., Osthaus 2017; Sovrano et al. 2018). Similarly, prey species can evade predators better by continuously updating their location and movement. Representing visible displacements also has benefits for social animals, such as when avoiding competition or keeping track of offspring without the requirement for constant perceptual feedback (Jaakkola 2014). Memory is crucial in all these situations and is clearly a limiting factor in visible displacement tasks that impose time delays (Cacchione and Rakoczy 2017; Many Primates et al. 2019).

Caching birds store, remember and retrieve many hidden food items to survive food-scarce periods. Hypotheses on species differences in object permanence abilities often invoke caching propensity, but the results are mixed (e.g., Ujfalussy et al. 2013; Zucca et al. 2007), which suggests that a different factor primarily drove the evolution of representing hidden objects. Animals may rely on various cues and heuristics that do not involve advanced levels of object permanence, as outlined in the next section. A possible explanation for species reaching later stages is that they may experience objects and agents disappearing in a large variety of contexts that warrants more flexible responses; a stereotypic or learned response might not suffice. Future studies should test such ecological and evolutionary hypotheses in more detail.

Invisible Displacement

Understanding an invisible displacement means tracking the movements of an object even when it is not directly perceivable (Cacchione and Rakoczy 2017; Piaget 1954; Singer 2018). Its occurrence and significance in nature may be rare because target objects are not often concealed by a moving "occluder." A baby marsupial in the mother's pouch is one example. Prey species often move when not perceivable by a predator, but this does not constitute invisible displacement as defined in the literature. For instance, a vole escaping through a burrow is not invisibly displaced in this sense because the "occluder" (i.e., the burrow) does not move. Instead of invisible displacement, a predator could use *trajectory extrapolation* to predict where the vole might end up (Jaakkola 2014; Johnson et al. 2015). Under most circumstances, the most adaptive response to something disappearing out of view may be searching where it was last seen, which would be a failure in most invisible displacement tests. The adaptive significance of invisible displacement is more often viewed as arising from broader representation or abstraction abilities than as an isolated skill (e.g., Collier-Baker et al. 2006; Suddendorf and Whiten 2001).

Mental *secondary representation* of an object is required to understand it continues to exist and can move when not perceivable (e.g., Fiset and LeBlanc 2007; Suddendorf and Whiten 2001). For example, a subject needs to appreciate the continued existence of the reward in the displacement device and that it moves with it in the standard Piagetian task. It also needs to understand that the reward can stay in the displacement device or move out of the device and stay behind the occluder (Cacchione and Rakoczy 2017). These are two hypothetical models that the subject needs to bear in mind and then infer which model is correct. Thus, this secondary representation adds the ability to mentally create hypothetical models, to conserve those multiple models, and to adjust them through deduction (Collier-Baker et al. 2006; Suddendorf and Whiten 2001). Secondary representation is defined as the capacity to consider multiple models of the world rather than relying only on immediate perception to guide behavior. It is a cognitively complex ability that only a few species have reached in Stage 6 object permanence tasks (e.g., Collier-Baker et al. 2006; Jaakkola et al. 2010; Jaakkola 2014; Singer and Henderson 2015; Zucca et al. 2007).

Many cognitive skills of humans have been linked to secondary representation, and it is therefore no surprise that they emergence at the same time during development (Cacchione and Rakoczy 2017; Suddendorf and Whiten 2001). Full object permanence develops in children around the age when they also develop mirror self-recognition, means-end reasoning, imitation, symbolic thought, and language (Collier-Baker et al. 2006; Jaakkola et al. 2010; Suddendorf and Whiten 2001). Most of these cognitive skills are also found to some extend in great apes and corvids, which is similar to the spread of full object permanence (Collier-Baker et al. 2004; Lambert et al. 2019; Suddendorf and Whiten 2001). Each skill is beneficial in a different way, but all fit under this wider representational umbrella. Although the adaptive significance of understanding invisible displacement is not well studied – and could be marginal due to such contexts being rare in nature – this perspective may better explain its evolution. However, it is also possible that these skills are a by-product of another cognitive skill that has not yet been recognized as such (Ujfalussy et al. 2013) or that successful test performance arises from cognitive "shortcuts" such as using cues and heuristics (see below). The methodology of object permanence tasks has therefore been regularly scrutinized.

Methodical Issues and Improvements

Piaget created a useful framework to test object permanence in many species. Although it is still used, it is also frequently criticized. Critics mainly call for conceptual clarification and reduction of alternative explanations through control experiments and analysis of multiple variables (e.g., Cacchione and Rakoczy 2017; Jaakkola 2014). Without control conditions, the cognitive abilities of successful subjects may be overestimated (false positives); there are numerous reasons why a subject performs well on a task, with representation of object permanence being one of many. The risk for false negatives should also be considered; animals with the ability in question may still perform poorly when the testing procedure is unsuitable or unnecessarily complex (e.g., Cacchione and Rakoczy 2017; Pepperberg 2002). As in all experimental paradigms, these risks need to be understood and balanced. The four main critiques are nonvisual perception, social cues, associative learning, and sensorimotor incompetence.

Nonvisual Perception

Humans are primarily visual creatures, so when we think of objects not being perceivable during tests, we intuitively think of them as being out of view sight. Although some cues are necessary for the subject to base the search on (e.g., perceiving the hiding process), other unintentional cues can still help subjects with perceiving hidden objects, which is a risk of any testing condition – especially when species are involved that have excellent nonvisual senses. These animals may appear to have outstanding object permanence abilities when they in fact perceive the hidden object in ways that experimenters failed to take into account.

Olfactory and Auditory Cues

Sound and odor are probably the most influential nonvisual cues in comparative research. Preventing these cues can be done in three main ways. First, study designs can aim to *minimize the presence of a cue*. For example, occluders can be made airtight or soundproof. The subject can also be separated from the experimental setup by a transparent wall that blocks these cues. Second, researchers can *oversaturate the setup with a cue*. In many studies, the scent of the reward is spread around all materials and will thereby mask the scent of the goal reward during testing (e.g., Zucca et al. 2007). Similarly, use of auditory cues can be minimized by playing ambient sounds during testing. Experimenters can also perform the same manipulations at each occluder, which should produce the same sounds in each case. Third, studies can actively *test for the influence of a cue*. This is typically done by secretly changing the location of the reward or by hiding it out of view of the subject. Thus, the subject cannot deduce the correct location with object permanence. Successful above-chance performance over repeated trials then suggests the subject located the reward through a nonvisual cue (e.g., Uzgiris and Hunt 1975; Zucca et al. 2007). These three methods of controlling for nonvisual cues can be used separately or combined (Collier-Baker et al. 2004).

Potential Influence of Other Senses

Smell and hearing are probably the most important senses to consider in a task design for object permanence. However, many animals have senses that humans do not possess or have a wider range and higher sensitivity of senses shared with humans (Keeley 2015). For example, some sharks and migratory birds can perceive magnetic fields, which makes it inappropriate to use magnets to hold and move objects and occluders (Jaakkola 2014). Echolocation is another sense that can distort results on object permanence tests (e.g., Keeley 2015; Singer and Henderson 2015). To minimize the use of echolocation, the test can be conducted in a different medium. For instance, testing materials were placed on land for cetaceans, so they could not use echolocation to find the hidden items (Jaakkola et al. 2010; Singer and Henderson 2015). Other potentially influencing senses are the ability of "remote touch" (where species use their specialized beaks to sense vibrations of nearby moving prey), detecting thermal infrared waves of objects, or sensing electric signals from the nerves of prey animals (Keeley 2015). The potential problem of these senses is species-specific, so it is important that experimenters are familiar with the sensory abilities of their study species. The kind of senses that representations are built on is another important line of enquiry: true object permanence means representing objects as permanent multimodal entities, but the question of whether animals recognize object cross-modally has received little attention.

Social Cues

Animals may also perform well on object permanence tasks by using social cues that are (unintentionally) produced by the experimenter. These cues are mainly found in gaze direction and body posture (Jaakkola 2014; Pepperberg 2002). Conspecifics may also provide inadvertent cues that reveal the location of a reward, so subjects should be tested in individual settings where possible. Controlling for social cues produced by humans and conspecifics is an important method to reduce the likelihood of false positives.

Four main methods are applied to prevent social cueing (Jaakkola 2014): shielding gaze direction, averting gaze, shielding body posture, and using multiple experimenters. First, experimenters can ensure that subjects cannot see their gaze by shielding their eyes. For example, the experimenter can wear mirrored sunglasses (Pepperberg et al. 1997) or a welding mask (Collier-Baker et al. 2006). This is also necessary for other people present, such as pet owners, who can be blindfolded (Collier-Baker et al. 2004). However, welding masks and mirrored sunglasses can distract or scare animals, which should therefore be well habituated to the shielding method. Some animals learn to find hidden food through reflections and mirror images, which needs to be avoided in this context. Furthermore, only humans appear to treat (human) gaze alone as a salient cue. Great apes tend to react more to head direction, whereas human infants focus mostly on gaze direction (Tomasello et al. 2007). Covering the experimenter's eyes will remove only gaze direction but not head direction as a cue. Thus, while most studies cover the experimenter's eyes to prevent gaze cues (Jaakkola 2014), this might not be sufficient as subjects may use head direction as a cue instead. A second control method is to have the experimenter look away from the setup (e.g., Zucca et al. 2007). Averting gaze can help against social cueing for both eye and head directions, although unintentional glances might occur as the experimenter needs to monitor and control the test. Furthermore, body posture can still give cues to the subject with both methods.

Third, the body of the experimenter can be shielded with a screen or curtain to avoid cuing with body posture (e.g., Collier-Baker et al. 2004; Fiset and LeBlanc 2007). Although this method reduces many social cues, it may also distract subjects when they are not familiar with partially occluded humans. A decrease in attention to important events during the experiment brings about a higher risk of a false-negative result. Moreover, the position of the experimenter can still be used as a cue. A fourth method is to use a *conductor-asker* setup (Jaakkola 2014). The conductor performs the experiment as usual but then leaves the room. The asker then enters the room and prompts the subject to make a choice. This asker does not know where the reward was hidden and thus cannot provide cues – not even cues that do not involve gaze or body posture. Although this setup makes sure that social cueing does not happen, it also complicates the task. It might be hard to teach the subject the procedure and to have it understand when it is "asked" to select or search. The switch of researcher may also be confusing or distracting. Moreover, there is a longer waiting period before a selection can be made, which may decrease performance and requires more inhibitory control (Cacchione and Rakoczy 2017; Osthaus 2017). Experiments that do not involve humans or rely less on demonstrations by an experimenter carry a lower risk for social cuing (see section "Violation of Expectation Studies").

Associative Learning and Strategies

Animals can learn to choose the correct occluder without representing the location of the hidden object (Cacchione and Rakoczy 2017; Collier-Baker et al. 2004; Jaakkola 2014; Singer and Henderson 2015). They will appear to possess object permanence but in fact merely act on learned associations, rules, biases, or heuristics. The ability to solve a task through these strategies risks a higher chance of false positives and should therefore be taken into consideration.

When representing object permanence, the subject is expected to solve each task rapidly with only a few trials to adjust to the setting. More trials will create a greater likelihood that subjects can learn an associative rule, which is a weakness of the Uzgiris and Hunt scales (Cacchione and Rakoczy 2017; Doré and Dumas 1987). Therefore, most studies use a minimal number of trials and look for learning effects, such as a positive correlation between trial number and performance (Doré and Dumas 1987; Jaakkola 2014). Learning may also explain better performance in conditions or stages that are tested later in a test sequence. This effect can be investigated by counterbalancing testing order across subjects. If they all perform better in later tasks, regardless of condition, a learning effect is apparent. Another suggested improvement to reduce associative learning is to never show the correct location of the reward after the subject has chosen the wrong occluder (e.g., Zucca et al. 2007). The advantage of this is that associative learning will become harder and there is a lower risk of carry-over effects between trials (e.g., selecting the occluder that was correct in the previous trial). However, this method may also reduce motivation. A stronger case for object permanence can be made when success is maintained across context, with different materials, rewards, experimenters, positioning, and conditions. Next to these general suggestions, many studies have also aimed to directly control for known associative rules.

Select the Occluder Manipulated by the Experimenter or Visited by the Displacement Device

Typical tests of object permanence are done by placing a reward in, under, or behind an occluder. Thus, only one occluder is manipulated by the experimenter or visited by the displacement device. In this context, a subject can be highly successful by always selecting the occluder that was manipulated last by the experimenter or visited by the displacement device (Doré and Dumas 1987). This can be avoided by manipulating all occluders and by letting the displacement device visit all occluders, preferably in a random order (Jaakkola 2014; Zucca et al. 2007). It is important that the experimenter performs a sham manipulation or transfer with every occluder, where similar actions to a normal manipulation or transfer are done, without actually transferring the reward. The saliency of the manipulation may also play a role. For instance, hiding a reward behind a stationary barrier or screen is likely a less salient cue than lifting an inverted cup, placing the reward, and then placing the cup over it. Placing two occluders simultaneously, with one thereby covering the previously visible stationary reward, is another approach. Nonetheless, subjects may still succeed by using associations or learned rules such as always searching in the general area where the reward was last seen, which would be an adaptive response under many natural circumstances. Similar to other methodological issues, eliminating potential cues is difficult – if not impossible – but they can be reduced.

Select the Occluder Last Visited by the Displacement Device

Using the order of events or manipulations can be another successful approach. Always selecting the occluder last visited will result in perfect performance when there are no movements after hiding the reward (Collier-Baker et al. 2004; Jaakkola 2014; Zucca et al. 2007). This can be countered with a *drop-first control* (Fig. 5a). For this control, the experimenter moves the baited displacement device behind an occluder, transfers the target reward behind the occluder, and shows the empty displacement device to the subject. The displacement device then continues to the next occluder where a sham transfer is performed, after which the subject is again presented with an empty displacement device. This sequence is repeated until all occluders have been visited by the displacement device (Collier-Baker et al. 2004; Jaakkola 2014; Zucca et al. 2007). A subject using the "select the last occluder visited" rule will never choose the correct location first.

Select the First Occluder Visited by the Displacement Device

Another frequently successful strategy is to choose the occluder first visited by the displacement device. In the *drop-last control* (Fig. 5b), the experimenter moves the baited displacement device behind an occluder, then performs a "sham transfer," and reveals the displacement device to be baited. This sequence is repeated at every location until the last occluder, where the reward is transferred behind the occluder. Following the *first-visited rule* will no longer be viable in this control. However, this control method is underrepresented in most studies, which weakens interpretations of full object permanence in invisible displacement tasks (Jaakkola 2014). Gaining more solid evidence is possible by testing an intermixed series of drop-first, drop-last, and maybe even drop-middle controls (Collier-Baker et al. 2004, 2006).

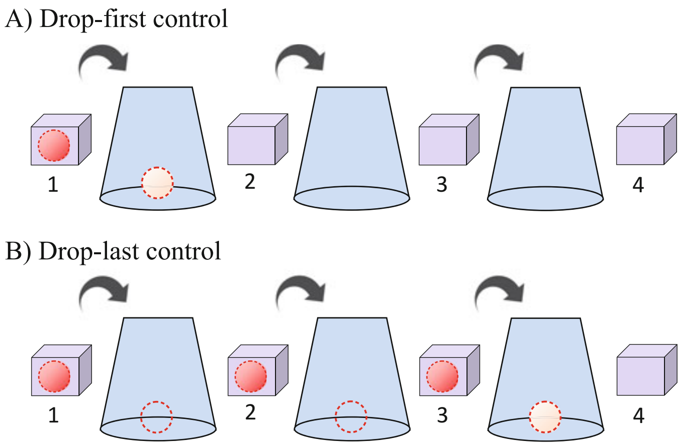
Select the Occluder Adjacent to the Displacement Device

Subjects that fail more complex object permanence tasks often attend closely to the location of the displacement device at the end of a trial (Cacchione and Rakoczy 2017; Collier-Baker et al. 2004). They tend to search the occluder adjacent to the displacement device first. These animals appear to link the displacement device to the reward and then search in its vicinity, using the position of the displacement device as a landmark that indicates the baited location (Fiset and LeBlanc 2007). The displacement device should be removed to reduce use of such spatial cues. Although results do not show consistent effects, chances of another possible associative strategy are reduced by removal of the displacement device before a choice can be made (Collier-Baker et al. 2004; Jaakkola et al. 2010).

These are some of the most common controls for associative learning, and more are possible. However, it should be noted that such tasks can become too complicated to solve and that subjects may not be attentive or motivated enough to participate in all conditions. Studies should be adjusted to the species, and a mindful balance between avoiding false positives and false negatives can be achieved by considering the effects of these confounding factors.

Sensorimotor Incompetence

The Piagetian tasks were originally designed for human children and proved a great inspiration for studies on other species. However, the difference between species in sensorimotor competences should not be neglected (Cacchione and Rakoczy 2017). These object permanence tasks are suitable only for visual species, even though understanding that objects endure is beneficial to less visually adept species, and tasks can be redesigned to suit them. These tasks also require animals to select an occluder or remove it. Selection by human infants is traditionally shown by uncovering an occluder with their hands (Piaget 1954). However, uncovering occluders is not always easy for animals that are less anatomically suited for such behaviors (e.g., Fiset and LeBlanc 2007). Therefore, the sensorimotor capacities of a species



Object Permanence, Fig. 5 **The drop-first and drop-last controls.** (**a**) The object is hidden in the displacement device and then transferred to one occluder. Then, the displacement device is shown to be empty, and it continues to the next occluder(s). (**b**) The object is hidden in the displacement device and then transferred to one occluder. This sequence is repeated for each occluder, and the reward is deposited behind the last occluder, after which the displacement device is shown to be empty. Dark objects are visible for the subject, transparent dots are intermediate positions, and light objects are in the final position

should be a key factor in study design. Selecting an occluder is generally easier than removing it. Each subject can first be trained to touch an occluder and receive the hidden reward before formal testing begins.

Although many researchers take the species-specific differences in physical competence into account, it is often overlooked how this competence differs within species, especially during development (Baillargeon 1987; Cacchione and Rakoczy 2017; Pepperberg 2002). These animals may fail on an object permanence task because they cannot remove or select their choice, but that does not mean they consider the hidden object to have vanished. Some studies have tried to minimize the demands on physical competence with a new group of methods: violation of expectation.

Violation of Expectation Studies

Contemporary theories of object cognition build on the Piagetian tradition but differ in substantial aspects. Core knowledge theorists postulate that cognition consists of several domain-specific core systems that represent fundamental aspects of the environment, such as objects, geometry, numbers, and agency. Much like adults, human infants represent objects as entities that are cohesive (enduring as discrete units), bounded (having a boundary that cannot be occupied by other objects), spatiotemporally continuous (persisting over time and space), and material (consisting of matter with mass). Each aspect of core object cognition – particularly spatiotemporal continuity – corresponds to some degree with Piagetian object permanence. Thus, developmental research often specifies what aspect is under investigation, rather than using the less specific term “object permanence.” Compared to the Piagetian framework, examining core knowledge is not as dependent on sensorimotor interactions and search behavior and therefore employs less action-based measures – such as looking time – that have lower motoric and executive demands (Baillargeon 1987; Cacchione and Rakoczy 2017).

Violation of expectation (VoE) studies compare how long subjects look at possible and impossible outcomes of an event. The possible outcome follows the expected persistence of objects across space and time. The impossible outcome does not follow these principles and is orchestrated through various secret manipulations.

Subjects are expected to look longer when "tricked" by the impossible outcome, compared to the possible outcome that closely resembles the impossible one (Baillargeon 1987; Müller et al. 2011). The rationale behind this method is that a subject will react similarly and look equally long to the possible and impossible outcomes when it does not have object permanence.

Developmental psychologists first designed VoE methods to study infants younger than the age at which they actively make choices in traditional Piagetian tasks. This benefit extends to animals, especially when they are similarly early in development or when the species is not suited for choice tasks. Although this procedure is less common than the standard Piagetian tasks, it holds many advantages, such as lower sensorimotor demands and reduction of social cues, nonvisual perception, and strategy use. Learning still occurs but forms an important component because subjects are expected to initially show great interest in the impossible outcome, which will diminish with increasing exposure (Baillargeon 1987; Cacchione and Rakoczy 2017). These benefits are especially welcome when studying infant animals; they merely need to attend to the event, which is possible after reaching Piagetian Stage 2. The VoE method is mainly applied in three components of object knowledge: continuity, constancy, and solidity.

Violation of Object Continuity

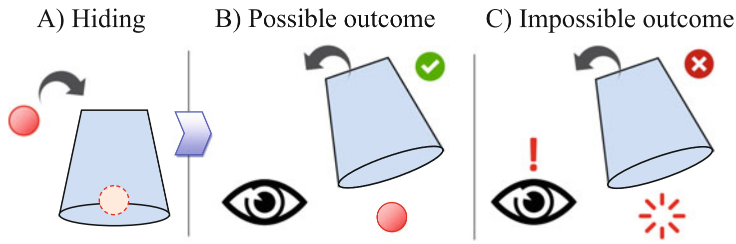
Object continuity is the principle that an object continues to exist independently of perception. This principle is under investigation in most traditional tests of object permanence. In VoE studies, a standard displacement task is performed, but the reward is secretly removed or moved to another occluder. A subject with sufficient understanding of object continuity will expect the reward to be behind the original occluder (Fig. 6b). When the experimenter uncovers the empty occluder in the impossible event (Fig. 6c), the subject may be "surprised," as revealed by longer looking times and other key behaviors such as strong arousal. In other words, its expectation was violated.

Although this paradigm comes closest to the standard Piagetian tasks, it has rarely been studied directly. Most comparative studies have used it as a control for nonvisual cueing, but few studies report the difference in reaction or looking times of the subjects between the possible and impossible outcomes (but see Zucca et al. 2007). Importantly, looking time is also used as a measure of expectation before the outcome occurs, which may or may not violate expectations. Here, the subject's predictions are revealed by where they look. For instance, this method has shown that bottlenose dolphins appear to predict the trajectory of occluded moving objects and the correct location of invisibly displaced objects (Johnson et al. 2015).

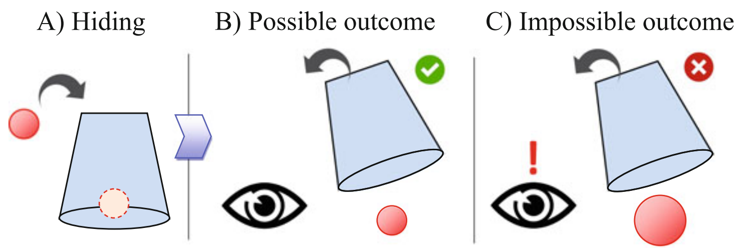
Violation of Object Constancy and Identity

Object constancy is the principle that the features of an object remain constant independently of perception; they do not change their appearance or turn into other objects (i.e., change identity). Typical object permanence tasks ask the subject to choose the correct location of an object, not its correct identity. Nonetheless, a subject that appreciates object permanence should also encode its features and should therefore not expect these features to change when temporarily out of view. This principle is often tested with size constancy, where the size of the target object either remains the same size (possible outcome; Fig. 7b) or is secretly changed (impossible outcome; Fig. 7c). For instance, female dogs looked significantly longer when the size of a ball changed after disappearing compared to it remaining the same, which suggests they relied on size constancy (Müller et al. 2011).

Recognizing the constancy of object identity is tested in a similar matter, except that the object is substituted with a different kind. Rhesus macaques and African gray parrots act surprised and often angry when finding food type A in a location where food type B was hidden and often reject A even though they would eat it immediately under normal circumstances (Pepperberg et al. 1997; Tinklepaugh 1928). Thus, they appear to represent the specific identity of the occluded



Object Permanence, Fig. 6 Violation of object continuity. (**a**) The target object (red circle) is hidden behind an occluder. The subject then watches either (**b**) a possible outcome, where the target object appears again, or (**c**) an impossible outcome, where the target object has seemingly disappeared. This method can further be combined with manipulations from traditional tests, such as visible and invisible displacement

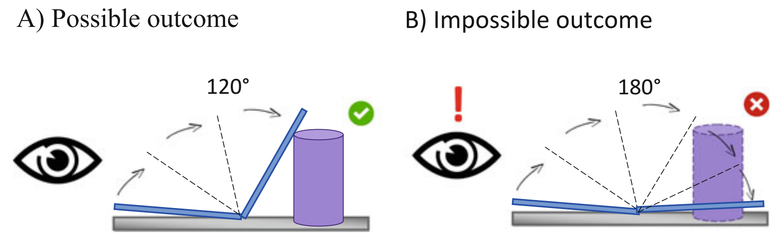


Object Permanence, Fig. 7 Violation of object constancy. (**a**) The target object (red circle) is hidden behind an occluder. The subject then watches either (**b**) a possible outcome, where the target object appears again, or (**c**) an impossible outcome, where the target object has seemingly changed in size

object and express surprise when its constancy is violated.

Violation of Object Solidity

Object solidity is the principle that multiple solid objects cannot occupy the same space at the same time. This principle naturally also applies when not directly perceived, such as an out-of-view object colliding with a visible object. Failure to represent this principle may arise from a deficient concept of object permanence in which objects can suddenly disappear or come into existence. The *drawbridge paradigm* is commonly used in this context (Baillargeon 1987; Singer and Henderson 2015). Here, subjects are shown a flat screen that can rotate 180°, from horizontally flat, to vertically upright, to horizontally flat again (Fig. 8). An object is placed behind the screen in such a way that when the screen is rotated 90° (vertically upright), the object is no longer visible for the subject. If the subject understands object permanence, it should know that the object is still present and that when the screen will be rotated further, it should hit the object and thus will not be able to rotate any further (Fig. 8a). In the impossible outcome, the object is secretly removed, and the screen fully rotates (Baillargeon 1987; Singer and Henderson 2015). The principle of object solidity prohibits such movements, which should surprise subjects that represent this principle when observing this seemingly impossible outcome (Fig. 8b). Surprise is again measured by increased looking time compared to the possible outcome. For instance, California sea lions and bottlenose dolphins look longer at the impossible event, just like human children, which suggests they have a concept of object solidity (Singer and Henderson 2015). Action-based versions involve a reward that is hidden out of view under one of two rigid boards. Reasoning about object solidity should lead a subject to choose the inclined board because the solidity of both the reward and board causes the inclination, and the reward cannot occupy the same space under a flat board.



Object Permanence, Fig. 8 Violation of object solidity (drawbridge paradigm). The screen (blue) rotates away from the subject (looking from the left) toward the object (purple). (a) The 120° rotation is the possible outcome, as the screen stops at the object. (**b**) The 180° rotation is the impossible outcome as the screen would have to move through the object (which had been secretly removed). (Adapted from Baillargeon 1987)

Some species have passed this test, but care should be taken to control for alternative explanations (Cacchione and Rakoczy 2017) and additional cognitive requirements, such as reasoning by exclusion (Klerk and Jacobs 2021).

Overall, these three VoE paradigms can test for different principles of object permanence (continuity, consistency, and solidity). They have been used to great success for investigating the object cognition of young infants and are promising yet underutilized tools in animal cognition.

Conclusion

Object permanence is a cognitive skill that has been extensively investigated in humans and other animals. The study of object permanence in animals builds on the foundational work of Piaget, who formulated a stepwise progression in the first years of a child's development. Although cognitive development is not frequently studied in animals, the six-stage Piagetian framework proved useful in documenting and comparing the highest stage that various species reach as adults. Through this comparison, we gain insight into the adaptive benefits of object permanence and its evolutionary history. However, the reliability of many results is heavily debated, which obscures the comparative power of this paradigm despite its widespread use. Therefore, conceptual clarifications are formulated, and methodological improvements are tested, with the resulting recommendations largely deviating from the Piagetian framework. Crucially, these changes in methodology should suit the species under investigation and aim to limit the effects of confounding factors and alternative explanations; the risks of false positives and false negatives form a trade-off that needs to be carefully navigated. Thus, the unique position of object permanence as a key cognitive ability has – with further conceptual and methodological development – a promising future after its long history.

Cross-References

▶ A-Not-B Problem
▶ Associative Learning
▶ Executive Function
▶ Invisible Displacement
▶ Modality
▶ Reasoning by Exclusion
▶ Short-Term Memory
▶ Social Learning
▶ Spatial Memory
▶ Violation of Expectation
▶ Visible Displacement

References

Baillargeon, R. (1987). Object permanence in 3½- and 4½-month-old infants. *Developmental Psychology, 23*, 655–664.

Barth, J., & Call, J. (2006). Tracking the displacement of objects: A series of tasks with great apes (*Pan troglodytes*, *Pan paniscus*, *Gorilla gorilla*, and *Pongo pygmaeus*) and young children (*Homo sapiens*). *Journal of Experimental Psychology: Animal Behavior Processes, 32*, 239.

Cacchione, T., & Rakoczy, H. (2017). Comparative metaphysics: Thinking about objects in space and time. In J. Call (Ed.), *APA handbook of comparative psychology: Perception, learning, and cognition* (Vol. 2, pp. 579–599). Washington, DC: American Psychological Association.

Collier-Baker, E., Davis, J. M., & Suddendorf, T. (2004). Do dogs (*Canis familiaris*) understand invisible displacement? *Journal of Comparative Psychology, 118*, 421–433.

Collier-Baker, E., Davis, J. M., Nielsen, M., & Suddendorf, T. (2006). Do chimpanzees (*Pan troglodytes*) understand single invisible displacement? *Animal Cognition, 9*, 55–61.

De Blois, S. T., Novak, M. A., & Bond, M. (1998). Object permanence in orangutans (*Pongo pygmaeus*) and squirrel monkeys (*Saimiri sciureus*). *Journal of Comparative Psychology, 112*, 137–152.

Doré, F. Y., & Dumas, C. (1987). Psychology of animal cognition: Piagetian studies. *Psychological Bulletin, 102*, 219–233.

Fiset, S., & LeBlanc, V. (2007). Invisible displacement understanding in domestic dogs (*Canis familiaris*): The role of visual cues in search behavior. *Animal Cognition, 10*, 211–224.

Jaakkola, K. (2014). Do animals understand invisible displacement? A critical review. *Journal of Comparative Psychology, 128*, 225–239.

Jaakkola, K., Guarino, E., Rodriguez, M., Erb, L., & Trone, M. (2010). What do dolphins (*Tursiops truncatus*) understand about hidden objects? *Animal Cognition, 13*, 103–120.

Johnson, C. M., Sullivan, J., Buck, C. L., Trexel, J., & Scarpuzzi, M. (2015). Visible and invisible displacement with dynamic visual occlusion in bottlenose dolphins (*Tursiops* spp). *Animal Cognition, 18*, 179–193.

Keeley, B. L. (2015). Nonhuman animal senses. In M. Matthen (Ed.), *The Oxford handbook of philosophy of perception* (pp. 853–870). Oxford, UK: Oxford University Press.

Klerk, S. M., & Jacobs, I. (2021). Reasoning by exclusion. In J. Vonk & T. K. Shackelford (Eds.), *Encyclopedia of animal cognition and behavior*. New York: Springer.

Lambert, M. L., Jacobs, I., Osvath, M., & von Bayern, A. M. P. (2019). Birds of a feather? Parrot and corvid cognition compared. *Behaviour, 156*, 505–594.

Majecka, K., & Pietraszewski, D. (2018). Where's the cookie? The ability of monkeys to track object transpositions. *Animal Cognition, 21*, 603–611.

Many Primates, Altschul, D. M., Beran, M. J., Bohn, M., Call, J., DeTroy, S., . . . Watzek, J. (2019). Establishing an infrastructure for collaboration in primate cognition research. *PLoS One*, *14*, e0223675.

Müller, C. A., Mayer, C., Dörrenberg, S., Huber, L., & Range, F. (2011). Female but not male dogs respond to a size constancy violation. *Biology Letters, 7*, 689–691.

Osthaus, B. (2017). A-not-B problem. In J. Vonk & T. K. Shackelford (Eds.), *Encyclopedia of animal cognition and behavior*. New York: Springer.

Pepperberg, I. M. (2002). The value of the Piagetian framework for comparative cognitive studies. *Animal Cognition, 5*, 177–182.

Pepperberg, I. M., Willner, M. R., & Gravitz, L. B. (1997). Development of Piagetian object permanence in grey parrot (*Psittacus erithacus*). *Journal of Comparative Psychology, 111*, 63–75.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.

Singer, R. (2018). Invisible displacement. In J. Vonk & T. K. Shackelford (Eds.), *Encyclopedia of animal cognition and behavior*. New York: Springer.

Singer, R., & Henderson, E. (2015). Object permanence in marine mammals using the violation of expectation procedure. *Behavioural Processes, 112*, 108–113.

Sovrano, V. A., Baratti, G., & Potrich, D. (2018). A detour task in four species of fishes. *Frontiers in Psychology, 9*, 2341.

Suddendorf, T., & Whiten, A. (2001). Mental evolution and development: Evidence for secondary representation in children, great apes, and other animals. *Psychological Bulletin, 127*, 629–650.

Tinklepaugh, O. L. (1928). An experimental study of representative factors in monkeys. *Journal of Comparative Psychology, 8*, 197–236.

Tomasello, M., Hare, B., Lehmann, H., & Call, J. (2007). Reliance on head versus eyes in the gaze following of great apes and human infants: The cooperative eye hypothesis. *Journal of Human Evolution, 52*, 314–320.

Ujfalussy, D. J., Miklósi, Á., & Bugnyar, T. (2013). Ontogeny of object permanence in a non-storing corvid species, the jackdaw (*Corvus monedula*). *Animal Cognition, 16*, 405–416.

Uzgiris, I. C., & Hunt, J. M. (1975). *Assessment in infancy: Ordinal scales of psychological development*. Champaign/Urbana: University of Illinois Press.

Zucca, P., Milos, N., & Vallortigara, G. (2007). Piagetian object permanence and its development in Eurasian jays (*Garrulus glandarius*). *Animal Cognition, 10*, 243–258.