Journal of Experimental Child Psychology 273 (2027) 106642

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

An agent's partial knowledge of a hidden array impacts infants' representations of object quantity

Jessica B. Applin, Melissa M. Kibbe *

Department of Psychological & Brain Sciences, Boston University, United States

ARTICLE INFO

Keywords:
Altercentric bias
Object representation
Catastrophic forgetting
Infancy
Ordinal choice
Theory of mind

ABSTRACT

Infants can represent the quantity of a set of hidden objects, but if the number of objects hidden in a location exceeds three, infants experience "catastrophic forgetting", failing to represent even a subset of the objects. Infants' representations of an object also are impacted by other agents' visual access to an object; infants represent what an agent observed about an object instead of what they themselves observed. Here, we asked whether an agent's partial visual access to a set of objects would impact infants' representations of the set's quantity, and if so, whether this impact would apply when infants' own representational limits are exceeded. Ten-14-month-olds ($n = 85$) completed an ordinal choice task in which they watched an experimenter distribute different quantities of crackers across two containers, and were allowed to crawl to one of the containers to obtain its contents. We manipulated whether the quantities hidden were within or outside of infants' capacity limits (1 vs. 2 or 1 vs. 4) and whether a second experimenter, who infants saw had also observed the crackers being distributed, had partial knowledge of the arrays (observing 1 vs. 1 or 1 vs. 2, respectively) or no knowledge. Infants' container choices suggested that they used the observing agent's perspective to represent quantity whenever she had partial knowledge of the arrays. Our results suggest that an agent's quantity representations may mandatorily supplant infants' own, and this may allow infants to represent a subset of objects in situations in which they would normally experience catastrophic representational failure.

Introduction

To maintain a stable representation of the world, infants must be able to keep track of objects as they become hidden from view. By at least 3.5 months of age, infants expect a hidden object to continue to exist when it is no longer visible (Baillargeon, 1987; Baillargeon & DeVos, 1991; Bower, 1967), and by at least 6 months can maintain a representation of the featural or categorical identity of a hidden object (Kibbe & Leslie, 2011, 2016, 2019; Wilcox, 1999). Infants' capacity to represent hidden objects improves significantly across the first three years of life (e.g., Cheng et al., 2019; Kibbe, 2015; Kibbe & Applin, 2022; Kibbe & Leslie, 2013; Zosh & Feigenson, 2009), with infants able to represent more details of more objects with increasing age.

However, infants' capacity to represent objects is limited by the number of hidden objects. This limit is well illustrated by infants' performance in studies using the ordinal choice method (e.g., Feigenson et al., 2002; Feigenson & Carey, 2005). In an ordinal choice task, infants (usually 10–13-month-olds) observe an experimenter hide individual food items (e.g., graham cracker sections) across two separate containers, with one container always holding a larger quantity of crackers than the other. Infants are then allowed to crawl

* Corresponding author.
E-mail address: kibbe@bu.edu (M.M. Kibbe).

https://doi.org/10.1016/j.jecp.2026.106642
Received 15 August 2025; Received in revised form 7 August 2026;
Available online 25 August 2026

toward one of the containers to retrieve its contents. The majority of infants select the container with the larger number of food items when given a choice between 1 and 2, 1 and 3, or 2 and 3 crackers, suggesting that they were able to concurrently maintain representations of the quantity of objects in each location and select the larger quantity to maximize their food reward. But when one of the locations contains 4 or more food items while the other contains fewer than 4, infants select the containers at random (Feigenson et al., 2002; Feigenson & Carey, 2005; vanMarle & Wynn, 2011). Indeed, infants fail to represent *any* of the hidden objects when the number of objects exceeds their object-tracking limit of three objects in a location (Feigenson & Carey, 2005). This pattern of "catastrophic" failure has been replicated using a variety of methods (for review, see Feigenson et al., 2004; Hyde, 2011; Mou & vanMarle, 2014; Kibbe, 2015; Wang & Kibbe, 2024) and is observed in infants up to at least 20 months of age (Barner et al., 2007; Mou et al., 2026).

Recent work has shown that infants' object representations also are impacted by *other agents' visual access* to objects (see Kibbe & Stahl, 2023, for review). This work suggests that infants' encoding of others' perspectives on objects can actually *supersede* infants' own perspective, a phenomenon identified by Southgate (2020; Kampis & Southgate, 2020) as an "altercentric bias" in infancy, which eases later in toddlerhood (Yeung et al., 2022; Southgate, 2024). For example, infants expect an object to be at the location it was last seen by another agent, even if the infant (but not the agent) observed the object subsequently moved to a different location (Kampis & Kovács, 2021; Kovács et al., 2010; Manea et al., 2023). Infants also encode an object's identity from an agent's perspective instead of their own perspective, even when their perspective on the object's identity differs from the agent's (Kampis & Kovács, 2021; Kampis et al., 2024). And the same neural areas are recruited when infants represent a hidden object and when infants observe another agent representing a hidden object (Kampis et al., 2015), suggesting that infants' own representations may share similarities with their representations of others' representations. Together, these results suggest that infants automatically compute other agents' representations of objects, and that these representations often overwrite infants' own representations of objects in the world. Southgate (2020) argues that this strong altercentric bias in infancy arises from the fact that human cognition is tuned to others' perspectives and minds (across the lifespan, Kampis & Southgate, 2020) combined with the fact that infants are still developing their own sense of self.

The previous research described above that showed an altercentric bias for object representation in infancy did so only for situations in which a single object was under consideration. That is, both the infant and the agent observed a single object, infants' and agents' perspectives differed about that single object, and infants' representation of that object appeared to be supplanted by the agent's perspective on that object. Furthermore, while an agent was present in the studies examining infants' representations of quantity described above (i.e., the experimenter distributing the crackers), the agent's perspective always matched the infants'. It is currently unknown whether and to what extent an agent's representations impact infants' representations of the *quantity* of objects hidden in a location.

On the one hand, infants' representations of small sets of objects are thought to be supported by the same representations they use to represent single objects (Feigenson et al., 2004; Hyde, 2011; Cheng & Kibbe, 2025). When infants encounter a small number of objects, they deploy unique object indexes to each individual object, tracking each object as it moves through space (Leslie et al., 1998; Kibbe & Leslie, 2026). If an agent's perspective on a single object impacts infants' representations of a single object, then an agent's perspective on a small set of single objects in a given location may also impact infants' representations of the quantity of objects in that location. That is, infants' own set of object index representations may be supplanted by the agent's. If that is the case, then infants who are faced with tracking greater than three objects in a location may fare better if an observing agent is aware of only a subset of those objects; that is, if the agent's perspective supplants infants' own representations, infants may be able to retain representations of some of the objects without experiencing catastrophic representational failure.

On the other hand, there are reasons to suppose that infants' own representational limits may complicate the altercentric picture. Even when the number of hidden objects is within infants' capacity limits (i.e., 3 or fewer), infants represent fewer details about objects when their attention must be spread across multiple objects (Kibbe & Leslie, 2013; Kibbe & Applin, 2022). As the number of things infants must attend to increases, including both objects and agents, infants may bump up against their own representational limits and have more difficulty effectively representing their own *or* others' representations. One study provides some support for this possibility. In Applin and Kibbe's (2019) study, infants were familiarized with an agent repeatedly reaching for one shape over another. The two shapes were then hidden behind separate occluders such that they were hidden from the infant but visible to the agent, and the infants heard a tone that indicated that the agent was about to reach. Infants reliably made anticipatory looks to the location of the goal object, but failed to notice when the object was revealed to have changed shape, suggesting that infants represented the agent's *action* on the object (predicting she would reach in a particular location), but subsequently failed to maintain a representation of the specific object hidden in that location. This study suggests that, when infants' attention is spread across a complex scene with multiple objects, they may default to encoding less information about objects. Furthermore, as infants' object tracking capacity limits are exceeded (i.e., when 4 or more objects are hidden in a location), it is unclear to what extent such representational limits may impact their ability to reliably encode other information from a complex scene, including agents' perspectives.

Do infants represent other agents' representations of quantity? And if so, does the total *number* of hidden objects affect whether an agent's perspective impacts infants' representations of quantity? Here, we asked whether an agent's partial knowledge of the quantity of objects hidden in a location would impact 10–14-month-old infants' behavior in an ordinal choice task, using a 2×2 experimental design.

Infants were assigned to a Within Capacity condition or an Outside Capacity condition. In the Within Capacity condition, an experimenter distributed two graham crackers in one location and one graham cracker in the other (within infants' object tracking limit), while in the Outside Capacity condition, an experimenter distributed four graham crackers in one location and one in the other (exceeding infants' object tracking limit). Additionally, within each condition, infants were assigned to either a Partial Knowledge condition or a No Knowledge condition. For infants in the Partial Knowledge condition, an agent seated next to the distributor watched her distribute the crackers across the two locations, but only observed half of the crackers in the larger set being hidden and became “distracted” while the remainder were hidden. This meant that in the Within Capacity condition, infants observed 2 vs. 1, while the observer observed 1 vs. 1, and in the Outside Capacity condition, infants observed 4 vs. 1, while the observer observed 2 vs. 1. For infants in the No Knowledge condition, the observer’s movements were identical to the Partial Knowledge condition, except that her eyes were closed throughout, so she did not observe any of the objects being hidden. Thus, the *only* difference between the Partial Knowledge and No Knowledge conditions was whether the agent’s eyes were open or closed, and therefore whether she observed any or none of the crackers being hidden.

This 2 × 2 design allowed us to examine how an agent’s partial knowledge of an array impacts infants’ behavior in an ordinal choice task, and whether this impact depends on whether the number of objects hidden in a location exceeds infants’ object tracking capacity limits. Specifically, we considered four possible hypotheses for the impact of an agent’s partial knowledge on infants’ behavior depending on the quantity of objects hidden, summarized in Table 1.

One hypothesis is that, while an agent’s perspective appears to overwrite infants’ own representations when tracking a single object, this might not extend to representations of quantity. This hypothesis supposes that the altercentric bias may arise in simple scenes (like when a single object is hidden in a single location), but may recede as scene processing becomes more complex, such as when a scene contains multiple hidden objects. Under this *no impact* hypothesis, an agent’s observation of the objects will not influence or supersede infants’ representations of quantity. Therefore, given our design we would expect infants to successfully select the larger quantity in the Within Capacity conditions and fail to reliably select the larger quantity in the Outside Capacity conditions, regardless of the observer’s knowledge (consistent with previous work that did not have an observer agent present; e.g., Feigenson et al., 2002; Feigenson & Carey, 2005).

A second hypothesis is that an agent’s perspective may overwrite infants’ representations of quantity, but only when the number of objects hidden is within infants’ object tracking capacity. It is possible that when the number of hidden objects is outside of infants’ object tracking capacity (and infants’ own object representations fail catastrophically; Feigenson & Carey, 2005; Wang & Kibbe, 2024), that this catastrophic failure could potentially extend to *all* representations of information in the scene that is not directly observable, including another agent’s perspective. Therefore, the *within-capacity impact* hypothesis predicts that infants in our design should succeed only in the Within Capacity No Knowledge condition, when the number of objects is within infants’ capacity and the observer’s knowledge is not interfering (a classic 2 vs. 1 success). Otherwise, this hypothesis predicts failure due to either catastrophic forgetting (both Outside Capacity conditions) or observer representation interference (Within Capacity Partial knowledge condition – observer represents 1 vs. 1).

A third hypothesis is that the agent’s observation of the objects impacts infants’ representations of quantity only when infants’ object tracking limits are exceeded (i.e. when 4 or more objects are hidden) but not when the number of objects hidden falls within their object tracking limit. That is, under situations in which infants’ representational capacity is exceeded, infants may represent an agent’s partial knowledge, preventing catastrophic failure, but they may not be obligated to do so when their representational capacities are not taxed. This hypothesis is consistent with previous work suggesting that infants may be able to take advantage of certain social cues, like agents’ affiliations, to group objects together, allowing them to represent more than three objects concurrently (e.g., Stahl & Feigenson, 2014; Stahl et al., 2023) The *strategic impact* hypothesis predicts that infants should succeed at every condition except the Outside Capacity No Knowledge condition – that is, they should use their own representations whenever possible (both Inside Capacity conditions) and take advantage of the agent’s partial knowledge when their capacity limits are overwhelmed (Outside Capacity Partial Knowledge condition).

A final hypothesis is that the agent’s representation of object quantity impacts infants’ representations irresistibly, regardless of the actual quantity of hidden objects. This hypothesis is consistent with the “altercentric bias” – that infants’ representations of an object’s location or identity is always superseded by an agent’s representation of that object, even when it conflicts with the infants’ own (e.g., Southgate, 2020; Kampis & Southgate, 2020). The *mandatory impact* hypothesis predicts that the altercentric bias would apply to representations of quantity as well, and that therefore infants should succeed in the Within Capacity No Knowledge condition (a 2 vs. 1 comparison from the infants’ perspective) and the Outside Capacity Partial Knowledge condition (a 2 vs. 1 comparison from the

Table 1
Quantities observed by the infant and the Observer in each condition, and hypothesized patterns of infants’ choices (✓ = majority of infants select the larger container; x = infants select the containers at random) under four candidate hypotheses for how the Observer may impact infants’ behavior.

	Within Capacity (2 vs. 1)		Outside Capacity (4 vs. 1)	
	Partial Knowledge	**No Knowledge**	**Partial Knowledge**	**No Knowledge**
Infant sees	2 vs. 1	2 vs. 1	4 vs. 1	4 vs. 1
Observer sees	1 vs. 1	Nothing	2 vs. 1	Nothing
Hypotheses				
No impact	✓	✓	x	x
Within-capacity impact	x	✓	x	x
Strategic impact	✓	✓	✓	x
Mandatory impact	x	✓	✓	x

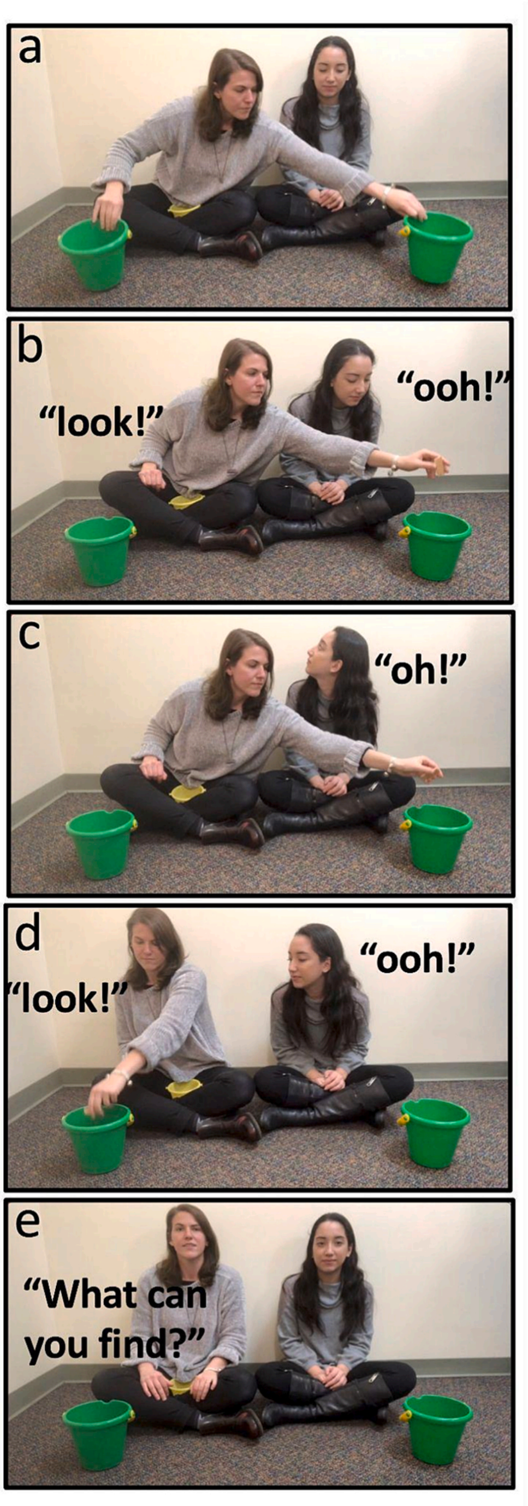

Fig. 1. Depiction of the actions of the Distributor (on the left) and the Observer (on the right) in the Partial Knowledge condition. The No Knowledge condition proceeded similarly, except the Observer's eyes were closed throughout.

agent's perspective), but should fail in the Within Capacity Partial Knowledge condition (a 1 vs. 1 comparison from the agent's perspective) and the Outside Capacity No Knowledge condition (a 4 vs. 1 comparison from the infant's perspective).

Method

Participants

Participants were $n = 85$ 10–14-month-old infants (mean = 12.3 months; range = 10.2 months – 14.3 months; 40 girls). Infants were recruited from the greater Boston area and were assigned to one of two between-participants Quantity conditions (a Within Capacity condition or an Outside Capacity condition), and within each Quantity condition were assigned to one of two between-participants Observer Knowledge conditions (Partial Knowledge of No Knowledge). This resulted in four total between-participants conditions (Within Capacity Partial Knowledge, $n = 25$; Within Capacity No Knowledge, $n = 24$; Outside Capacity Partial Knowledge, $n = 18$; Outside Capacity No Knowledge, $n = 17$).

Data were collected between 2015 and 2020, at which point data collection was abruptly stopped due to the Covid-19 pandemic, which made it impossible to continue testing infants in person with agents' and experimenters' faces in full view. Sample size was determined prior to data collection based on a review of previous literature that used the ordinal choice method, all of which included $n = 16$ infants per experimental condition (for meta-analysis and effect size estimates for ordinal choice tasks, see Wang & Kibbe, 2024). A priori, we aimed to exceed 16 infants for each of our conditions, including at least 18 infants per condition, with the goal of having a fairly even distribution of infants across the age range in each condition. We met our intended sample size of 18 or greater in three of our four conditions, and exceeded 16 but fell one short of our goal of 18 in our Outside-Capacity No Knowledge condition before data collection was disrupted by the pandemic.

An additional 41 infants were tested but were excluded from the experiment due to parental interference (2), experimenter error (6), standing or walking to the containers (such that they could see what was inside before choosing; 7), or failure to approach a container during either the warm-up or test trial (26). The study was approved by the Boston University Charles River Campus Institutional Review Board (protocol #3594E).

Materials

Materials consisted of two containers (green sand pails, 20 cm across × 18 cm tall) into which could be hidden graham cracker sections (approximately 6 × 3 cm each). The experimenter wore a bell-covered bracelet on her right hand to guide infants' attention toward each cracker as it was hidden. To familiarize infants with the procedure, we also used a smaller container (a yellow sand pail, 13.5 cm across x 12.5 cm tall) and a set of plastic toy keys. The yellow container also was used to hold the to-be-distributed crackers during the test trial.

Procedure

Infants were seated on the floor with their caregiver behind them, approximately 1.5 m from two experimenters, the Distributor and the Observer. Caregivers were instructed to hold their infants securely until the Distributor gave a verbal cue ("What can you find?") at which point they were instructed to release their infants and let them crawl.

Warm-up trial. Infants first completed a single warm-up trial. The Distributor and Observer first turned to each other. The Distributor waved to the Observer and said "Hi!" and the Observer responded by waving back and saying "Hi!" The Distributor then placed the yellow container at a center point between herself and the Observer, about 1 m from the infant. She showed the infant the set of plastic keys, shook them, and said, "Look at this!" She then hid the keys inside the container, looked at the infant and said "What can you find?", and then returned her gaze to the container. The Observer kept her gaze fixed on the container throughout the Distributor's actions. Once the infant crawled to the container and retrieved the keys, the Distributor said "Yay, great job!", gently took the keys from the infant, and placed the container and keys behind her back out of view. The caregiver was then instructed to return the infant to the floor in front of their lap and hold them securely. If an infant was reluctant to approach the container, the Distributor provided encouragement, repeating the verbal prompt and removing, shaking, and replacing the keys. If the infant still refused to approach the container after several prompts, the study was terminated. Infants who completed the warm-up trial proceeded to the single test trial.

Test trial. In the Partial Knowledge condition (Fig. 1), the Distributor held up the two green containers and said "Look at this!", and then showed the insides of the containers so that infants could see they were both empty. She then placed the containers simultaneously on the floor about 1 m apart (Fig. 1a), and proceeded to distribute crackers between the two containers.

The order of placement (whether the larger set was placed first or last) and side of the placement (whether the larger set was hidden in the left or the right container) was counterbalanced across infants. For illustrative purposes, here we describe the condition in which the larger set (either 2 or 4) was placed first and on the infant's right and the set of 1 was placed last and on the infant's left (as shown in Fig. 1).

The Observer directed her attention to the right-side container and said "Ooh!" (Fig. 1b). The Distributor then proceeded to place crackers in the right-side container. She held up the first cracker in the air between the two containers, looked at the infant and said "Look!" while jingling the bells around her wrist, and then placed the cracker in the container (Fig. 1b). She then proceeded to hide the remaining crackers in the larger set, holding each in the center and jingling her wrist before placing the cracker in the container (the

Distributor only said “Look!” when the first cracker in the set was hidden). After the Distributor had placed *half* of the larger set (1 cracker in the Within Capacity condition, 2 crackers in the Outside Capacity condition), the Observer said “Oh!” in a tone suggesting she had forgotten something, and turned her head to look up and away from the Distributor and the containers (Fig. 1c). Once the Distributor had hidden the remaining crackers in the larger set (an additional 1 cracker in the Within Capacity condition, an additional 2 crackers in the Outside Capacity condition), the Observer returned her gaze to a neutral point between the two containers. She then said “Ooh!” and directed her gaze to the left-side container, and the Distributor looked at the infant and said “Look!” and placed the single cracker in the left-side container (Fig. 1d). The Distributor then looked at the infant and said “What can you find?” (Fig. 1e), and both Distributor and Observer returned their gaze to a neutral point on the floor between the two containers to avoid influencing infants’ container choice.

Once infants touched a container, the experiment ended, and infants were allowed to eat a cracker (with caregiver permission). If an infant was reluctant to crawl, the Distributor repeated the prompt, “What can you find?” If the infant did not crawl after several prompts, they were excluded from analysis.

The No Knowledge condition proceeded similarly to the Partial Knowledge condition, with the following exceptions. The Distributor and Observer first greeted each other, as described above. The Observer then closed her eyes. The Distributor asked, “Can you see me?” and the Observer replied, “No, I can’t see anything!” The Observer then kept her eyes closed for the entire experiment. All of the Observer’s movements and vocalizations in the No Knowledge condition were otherwise identical to the Partial Knowledge condition: With her eyes closed, the Observer oriented toward each container as the Distributor began placing crackers in that container and said “Ooh!”, and after the first half of the larger set was hidden, the Observer turned her head away and said “Oh!”, returning her attention to the center after the remainder of the larger set was hidden.

Crucially, in all conditions, the Distributor ensured that infants observed the entire trajectory of each cracker from the moment the cracker was shown to the infant, to the moment it was placed inside one of the containers (as is common practice for ordinal choice tasks; see, e.g., Feigenson & Carey, 2005). The Distributor first drew infants’ attention to each cracker by waving the cracker slightly while jingling the bells she wore around her wrist, and then continued to gently jingle the bells as she moved the cracker into its container. The Distributor observed infants’ gaze direction throughout to make sure the infant was watching, and if necessary, jingled the bells more vigorously and said “Look! Look at this!” until infants’ attention returned to the cracker.

The quantities observed by the infant and the Observer in the four different conditions are shown in Table 1. In the Within Capacity conditions, the infant observed 1 versus 2 crackers hidden, and the Observer witnessed 1 versus 1 (Partial Knowledge) or nothing (No Knowledge). In the Outside Capacity conditions, the infant observed 1 versus 4 crackers hidden, and the Observer witnessed 1 versus 2 (Partial Knowledge) or nothing (No Knowledge).

Experimental sessions were video recorded. Infants’ container choice (whether they chose the larger set or the set of 1) was coded from video by trained research assistants who were naïve to which container held the larger quantity. The distance between the containers was such that infants were unable to touch two containers simultaneously. Therefore, there were no disagreements in which container infants selected. If infants selected one container, and then crawled to the second container, their first choice was used.

Analysis approach and hypotheses

Our primary analysis is a nominal logistic regression on infants’ container choice with Quantity (Within Capacity or Outside Capacity) and Observer Knowledge (Partial Knowledge or No Knowledge) as factors. This two by two experimental design allowed us to consider four possible hypotheses for the role of the Observer’s knowledge in infants’ behavior across the different quantity conditions. The four hypotheses, and predicted patterns of infants’ container choices under each hypothesis, are summarized in Table 1. We summarize the predicted statistical outcomes for each hypothesis, below.

Under the *no impact hypothesis*, we would predict no effect of the Observer’s knowledge on infants’ choices. Support for this hypothesis would come from observation of a main effect of Quantity with no main effect of Observer Knowledge and no interactions. That is, infants should select the larger quantity when the quantity comparison is within their object tracking capacity (2 vs. 1), but choose randomly when the quantity comparison is outside of their tracking capacity (4 vs. 1), regardless of the Observer’s knowledge, replicating previous studies using ordinal choice that did not have an observer present (e.g., Feigenson et al., 2002; Feigenson & Carey, 2003, vanMarle & Wynn, 2011).

Under the *within-capacity impact hypothesis,* we would predict that the Observer’s knowledge only impacts infants’ choices when the number of hidden objects falls within infants’ object tracking limit; otherwise, they experience a catastrophic representational failure that extends to all representations, including their representation of the agent’s representations. Support for this hypothesis would come from a main effect of Quantity, with infants selecting the containers randomly in both the Observer conditions when the quantity comparisons are outside capacity (4 vs. 1), and an interaction between Quantity and Observer Knowledge, with infants selecting the larger quantity in the Within Capacity condition (2 vs. 1) only when the Observer has no knowledge of the array, but not when the Observer has partial knowledge (such that they observed 1 vs. 1).

Under the *strategic impact hypothesis,* we would predict that the Observer’s knowledge only impacts infants’ choices when the quantity comparison exceeds infants’ object tracking capacity. Support for this hypothesis would come from a main effect of Quantity, with infants selecting the larger quantity in both the Observer conditions when the quantity comparisons are within capacity (2 vs. 1), and an interaction between Quantity and Observer Knowledge, with infants selecting the larger quantity in the Outside Capacity condition (4 vs. 1) only when the Observer has partial knowledge of the array (and therefore observed 2 vs. 1).

Under the *mandatory impact hypothesis*, we would predict that the Observer’s knowledge impacts infants’ choices whenever the Observer *has* partial knowledge of the contents of the arrays, regardless of whether the total number of objects falls within or outside infants' object tracking limit. Support for this hypothesis would come from observation of an interaction between Quantity and Observer Knowledge with no main effects. Specifically, we would expect infants to select the larger container in the Within Capacity No Knowledge condition (in which the infant sees 2 vs. 1 and the observer sees nothing) and in the Outside Capacity Partial Knowledge condition (in which the infant sees 4 vs. 1 and the Observer sees 2 vs. 1), but infants should choose randomly in the Within Capacity Partial Knowledge knowledge condition (when the infant sees 2 vs. 1 but the Observer sees 1 vs. 1) and in the Outside Capacity No Knowledge condition (when the infant sees 4 vs. 1 and the Observer sees nothing).

While our primary analysis of interest examined condition-based effects on infants' choice behavior, we also conducted a secondary analysis comparing infants' choices within each condition to chance (.5) using directional, one-tailed binomial tests. We included these directional tests since previous work that has used the ordinal choice method includes such tests, thereby facilitating comparison with other papers (e.g., Feigenson et al., 2002; Feigenson & Carey, 2005; Mou et al., 2026; vanMarle & Wynn, 2011; vanMarle et al., 2016). Specifically, these analyses test the directional hypothesis that, within a condition, infants either chose the containers at random (~50 % of infants choosing the larger set), or they chose the container with the larger quantity (> 50 % of infants choosing the larger set).

This study was not preregistered. All analyses were conducted in SPSS and all measures are reported. Data are available at https://osf.io/numjr/overview?view_only=1e4554a5ce174ecb839ad626130f3660.

Results

For our primary analysis, we analyzed infants' choices using a nominal logistic regression with Quantity (Within Capacity or Outside Capacity) and Observer Knowledge (Partial Knowledge or No Knowledge) as between-participants factors. We observed no main effect of Quantity ($X^2 = .45$, $p = .503$) or Observer Knowledge ($X^2 = .81$, $p = .368$). We did observe a significant interaction between Quantity and Observer Knowledge ($X^2 = 9.95$, $p = .002$). Adding infants' age in days as a covariate resulted again in a significant Quantity X Observer interaction ($X^2 = 11.63$, $p < .001$), but no effects relating to Age. The results of this analysis, and inspection of Fig. 2, suggests that infants' choices across conditions were consistent with the *mandatory impact* hypothesis.

For our secondary analyses, we followed this up with directional tests comparing infants' choices to random guessing. A majority of infants selected the larger quantity in the Within Capacity No Knowledge condition (when infants saw 1 vs. 2 and the Observer saw nothing; 17/24 infants, binomial test $p = .032$, one-tailed) and in the Outside Capacity Partial Knowledge condition (when infants saw 1 vs. 4 but the Observer saw 1 vs. 2, 16/19 infants, binomial test $p = .002$, one-tailed), while infants' choices were closer to random in the Within Capacity Partial Knowledge condition (when infants saw 1 vs. 2 but the Observer saw 1 vs. 1, 11/25 infants, binomial test $p = .345$, one-tailed) and in the Outside Capacity No Knowledge condition (when infants saw 1 vs. 4 but the Observer saw nothing; 11/25 infants, binomial test $p = .315$, one-tailed).

Discussion

Previous research has shown that infants can represent multiple hidden objects, but their representations fail "catastrophically" when the number of hidden objects exceeds three (Feigenson & Carey, 2003, 2005; Wang & Kibbe, 2024). Previous research also has

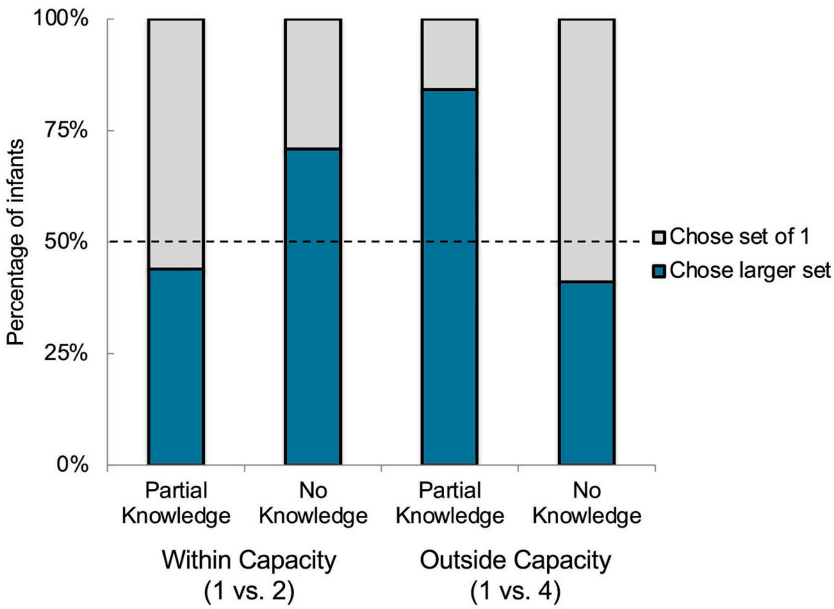

Fig. 2. Percentage of infants choosing the larger set or the set of 1 cracker across the four experimental conditions. The dashed line represents the percentage that would be expected if infants were choosing randomly (50 %).

shown that infants' own representations of a single object also can be overwritten by another agent's perspective on an object (Southgate, 2020;). Here, we asked whether and to what extent infants' representations of quantity are impacted by another agent's partial knowledge of the number of hidden objects in a location when the number of objects hidden in a location was within or exceeded infants' object tracking limit.

Our results provide support for the hypothesis that infants automatically use an agent's representation of quantity instead of their own in an ordinal choice task, at least under the conditions tested here. When an agent represented one container as containing more than the other, infants chose the larger quantity, even when the number of objects in that location exceeded infants' own object tracking limit. However, when an agent represented the two containers as containing the same quantity, infants chose randomly, even when the number of objects in the locations was within infants' object tracking limit. When the agent did not have visual access to the arrays, infants showed the typical pattern of behavior in an ordinal choice task without an observer agent present.

We suggest that infants represent another agent's quantity representations irresistibly (consistent with the altercentric bias hypothesis of Southgate, 2020), and that these representations overwrite their own representations of quantity. Further, these representations can actually scaffold infants in situations when they would typically be overwhelmed by their own object tracking limitations. This mandatory offloading of representation onto others is powerful, because it allows infants to retain something about an array when they typically would retain nothing, providing a more stable representation of the world (albeit a possibly non-veridical representation) that infants can use to guide behavior and learning.

Are there other possible explanations for infants' behavior? Previous research suggests that infants can use perceptual cues like sounds or spatial separation of sets to "chunk" sets of objects and exceed their object tracking limits (e.g., Feigenson & Halberda, 2008). The observer's movement and sound could have provided infants with such chunking cues, allowing them to group objects in the larger set to help them represent the entire set. However, we think this possibility is unlikely, since the agent's motions and sounds were equated across Knowledge conditions – if the agent's sounds and movement prompted infants to chunk the array, they should have been able to use those cues in both of the Knowledge conditions in the Outside Capacity condition, and infants should have succeeded in both Within Capacity conditions as well.

A more plausible alternative explanation is that infants in the Partial Knowledge conditions may not have actively represented another agent's representation. Instead, they may have used the agent's gaze direction as a cue to pay attention to only a subset of the objects. That is, when the agent was watching the array being hidden, infants may have focused on the agent, but when the agent looked away, infants may have focused on the objects being hidden. This would mean that infants only represented the objects that were hidden when the agent wasn't paying attention. However, we think this possibility is unlikely for a few reasons. First, the experimenter who distributed the crackers made sure that infants' attention was on each cracker, and ensured that infants looked at and followed the full path of each cracker as it was hidden. Second, if infants only attended to the arrays when the agent was not paying attention, we would expect infants to select the larger container in *both* Partial Knowledge conditions, since the choice in both conditions would be between something and nothing. However, this is not what we observed (Fig. 2).

A related possible alternative explanation is that, for infants in the Partial Knowledge condition, the agent's diverted attention away from the containers may have simply "reset" the scene for infants. That is, while infants may have fully attended to each object, they may have retained representations only of the objects that were hidden *after* the agent looked away. We also think this possibility is unlikely. In previous studies examining infants' representations of objects (e.g., manual search tasks; Wang & Kibbe, 2024), a single experimenter typically engages with the infants and the objects, and then diverts their gaze away from the scene (e.g., by looking down) to avoid influencing infants' behaviors during the measurement period. In those studies, the disengagement is abrupt and highly salient, but infants' behaviors suggest that they have maintained representations of the objects in the scene (e.g., they search inside a box for missing objects following the experimenter's abrupt disengagement). Further, on a practical note, if shifts in agents' attention lead to an obliteration of previous representations for infants, it would be very difficult indeed for infants to make sense of others' actions (see Kibbe & Stahl, 2023 for related discussion). Nevertheless, this possibility is consistent with the results we observed, and further research is needed to experimentally rule it out.

One puzzling aspect of our study, and indeed other studies that have shown altercentric biases in infants (e.g., Kampis & Kovács, 2021; Southgate et al., 2007), is that there were *two* other minds that had access (or not) to the arrays of objects: in our case, the Distributor (who had the same knowledge as the infant) and the Observer (whose knowledge differed from the infant's). Why did infants appear to represent the Observer's perspective on the arrays rather than the Distributor's? One possibility is that infants preferentially attend to the mental states of agents whose perspectives appear to differ from their own (for extensive discussion, see Southgate, 2020; Kampis & Southgate, 2020). Since representing and selecting among multiple agents' mental states is challenging for children (Leslie et al., 2004), infants may allocate limited attentional resources to an agent that appears to have differential access to a scene, thereby making better use of their limited representational resources. For infants who are still developing the distinctions between minds (including their own and others'), this may consequently mean encoding the scene from that agent's perspective rather than their own. Further work is needed to better understand the range of cues that infants' may use (e.g., the agent's gaze direction or focus of attention) in situations where the agent's and infants' perspectives conflict, or in situations in which an agent is present but has no access to information in the scene.

Future work is also needed to investigate the limits on infants' mandatory offloading of representation of quantity onto other agents. For example, in our study, the agent's representation of quantity always fell within infants' own object tracking limit. It is currently unknown whether such a limit applies to infants' representations of an agent's quantity representation. There also are open questions about how long infants are subject to the mandatory impact of another agent's perspective before they shift to a more mature ability to manage both their own and others' perspectives. Southgate (2020) suggests that the altercentric bias eases in toddlerhood. In our study, the agent's perspective appeared to impact infants similarly across our age range (see also Kampis & Kovács, 2021, for evidence of an altercentric bias in 14-month-olds), but other studies using more simplified scenes suggested that the altercentric bias begins to recede at least around 12 months (Manea et al., 2023). It is possible that the complexity of the scene or the complexity of the information infants must represent could "push around" the altercentric bias in toddlerhood. Future work should examine the extent to which the altercentric bias is impacted by the representational demands of a task.

This work also has some limitations. Although our overall sample size was sufficient for our planned analyses, the sample sizes within each condition, while comparable or greater than previous work that has used the ordinal choice method (e.g., Feigenson & Carey, 2005; Feigenson et al., 2002; vanMarle & Wynn, 2011; see Hyde, 2011; Wang & Kibbe, 2024, for review), were fairly small, and the sample itself is limited to infants in the greater Boston area. We also used a single method – ordinal choice – which requires infants to track two sets into occlusion and execute a crawling behavior to make a choice. Further work is needed to evaluate the strength and generality of these findings beyond the sampling approach and method tested here.

CRediT authorship contribution statement

Jessica B. Applin: Writing – review & editing, Methodology, Investigation, Funding acquisition, Conceptualization. **Melissa M. Kibbe:** Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to Michaela Buckley, Olivia Soledad, Alexis Smith-Flores, and Katie Hrper for their assistance with data collection. This research was supported by a Boston University Clara Mayo Memorial Fellowship Award to J.B.A.

Data availability

Data are available at https://osf.io/numjr/.

References

Applin, J. B., & Kibbe, M. M. (2019). Six-month-old infants predict agents' goal-directed actions on occluded objects. *Infancy, 24*(3), 392–410.
Baillargeon, R. (1987). Object permanence in 3½-and 4½-month-old infants. *Developmental Psychology, 23*(5), 655.
Baillargeon, R., & DeVos, J. (1991). Object permanence in young infants: Further evidence. *Child Development, 62*(6), 1227–1246.
Barner, D., Thalwitz, D., Wood, J., Yang, S. J., & Carey, S. (2007). On the relation between the acquisition of singular–plural morpho-syntax and the conceptual distinction between one and more than one. *Developmental Science, 10*(3), 365–373.
Bower, T. G. R. (1967). The development of object-permanence: Some studies of existence constancy. *Perception & Psychophysics, 2*(9), 411–418.
Cheng, C., & Kibbe, M. M. (2025). What kinds of computations can young children perform over non-symbolic representations of small quantities? *Open Mind, 9*, 25–46.
Cheng, C., Kaldy, Z., & Blaser, E. (2019). Two-year-olds succeed at MIT: Multiple identity tracking in 20-and 25-month-old infants. *Journal of Experimental Child Psychology, 187*, 104649.
Feigenson, L., & Halberda, J. (2008). Conceptual knowledge increases infants' memory capacity. *Proceedings of the National Academy of Sciences, 105*(29), 9926–9930.
Feigenson, L., & Carey, S. (2003). Tracking individuals via object-files: Evidence from infants' manual search. *Developmental Science, 6*(5), 568–584.
Feigenson, L., & Carey, S. (2005). On the limits of infants' quantification of small object arrays. *Cognition, 97*(3), 295–313.
Feigenson, L., Carey, S., & Hauser, M. (2002). The representations underlying infants' choice of more: Object files versus analog magnitudes. *Psychological Science, 13*(2), 150–156.
Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences, 8*(7), 307–314.
Hyde, D. C. (2011). Two systems of non-symbolic numerical cognition. *Frontiers in Human Neuroscience, 5*, 150.
Kampis, D., & Kovács, Á. M. (2021). Seeing the world from others' perspective: 14-month-olds show altercentric modulation effects by others' beliefs. *Open Mind, 5*, 189–207.
Kampis, D., & Southgate, V. (2020). Altercentric cognition: How others influence our cognitive processing. *Trends in Cognitive Sciences, 24*(11), 945–959.
Kampis, D., Parise, E., Csibra, G., & Kovács, Á. M. (2015). Neural signatures for sustaining object representations attributed to others in preverbal human infants. *Proceedings of the Royal Society B: Biological Sciences, 282*(1819), Article 20151683.
Kampis, D., Askitis, D., Poulsen, E., Parise, E., & Southgate, V. (2024). 14-month-old infants detect a semantic mismatch when occluded objects are mislabeled. *Infancy, 29*(4), 510–524.
Kibbe, M. M. (2015). Varieties of visual working memory representation in infancy and beyond. *Current Directions in Psychological Science, 24*(6), 433–439.
Kibbe, M. M., & Leslie, A. M. (2026). Minimal object representations in the infant mind: Structure, format, and inceptual role. *Evolution and Human Behavior, 47*(5), 106950.
Kibbe, M. M., & Applin, J. B. (2022). Tracking what went where across toddlerhood: Feature-location bound object representations in 2-to 3-year-olds' working memory. *Child Development, 93*(6), 1713–1726.
Kibbe, M. M., & Leslie, A. M. (2013). What's the object of object working memory in infancy? Unraveling 'what'and 'how many'. *Cognitive Psychology, 66*(4), 380–404.
Kibbe, M. M., & Leslie, A. M. (2016). The ring that does not bind: Topological class in infants' working memory for objects. *Cognitive Development, 38*, 1–9.
Kibbe, M. M., & Leslie, A. M. (2019). Conceptually rich, perceptually sparse: Object representations in 6-month-old infants' working memory. *Psychological Science, 30*(3), 362–375.
Kibbe, M. M., & Stahl, A. E. (2023). Objects in a social world: Infants' object representational capacity limits are shaped by objects' social relevance. *Advances in Child Development and Behavior, 65*, 69–97.
Kovács, Á. M., Téglás, E., & Endress, A. D. (2010). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science, 330*(6012), 1830–1834.

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998). Indexing and the object concept: developing "what" and "where" systems. *Trends in Cognitive Sciences, 2*(1), 10–18.
Leslie, A. M., Friedman, O., & German, T. P. (2004). Core mechanisms in 'theory of mind'. *Trends in Cognitive Sciences, 8*(12), 528–533.
Manea, V., Kampis, D., Grosse Wiesmann, C., Revencu, B., & Southgate, V. (2023). An initial but receding altercentric bias in preverbal infants' memory. *Proceedings of the Royal Society B, 290*(2000), Article 20230738.
Mou, Y., & vanMarle, K. (2014). Two core systems of numerical representation in infants. *Developmental Review, 34*(1), 1–25.
Mou, Y., Yao, X., Wu, J., & Zhao, S. (2026). The developmental change of infants' comparison between small and large sets. *Child Development, aacag041*.
Southgate, V. (2020). Are infants altercentric? The other and the self in early social cognition. *Psychological review, 127*(4), 505.
Southgate, V. (2024). The origins and emergence of self-representation. *Annual Review of Developmental Psychology, 6*.
Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science, 18*(7), 587–592.
Stahl, A. E., & Feigenson, L. (2014). Social knowledge facilitates chunking in infancy. *Child development, 85*(4), 1477–1490.
Stahl, A. E., Pareja, D., & Feigenson, L. (2023). Early understanding of ownership helps infants efficiently organize objects in memory. *Cognitive Development, 65*, Article 101274.
VanMarle, K., & Wynn, K. (2011). Tracking and quantifying objects and non-cohesive substances. *Developmental Science, 14*(3), 502–515.
VanMarle, K., & Wynn, K. (2011). Tracking and quantifying objects and non-cohesive substances. *Developmental Science, 14*(3), 502–515.
vanMarle, K., Mou, Y., & Seok, J. H. (2016). Analog magnitudes support large number ordinal judgments in infancy. *Perception, 45*(1–2), 32–43.
Wang, J., & Kibbe, M. M. (2024). "Catastrophic" set size limits on infants' capacity to represent objects: A systematic review and Bayesian meta-analysis. *Developmental Science, 27*(4), Article e13488.
Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition, 72*(2), 125–166.
Yeung, E., Askitis, D., Manea, V., & Southgate, V. (2022). Emerging self-representation presents a challenge when perspectives conflict. *Open Mind, 6*, 232–249.
Zosh, J. M., & Feigenson, L. (2009). Beyond 'what' and 'how many': Capacity, complexity and resolution of infants' object representations. *The origins of object knowledge*, 25-51.