

**Expectations of Rationality in Rhesus Macaques
(*Macaca mulatta*) and Dogs (*Canis familiaris*)**

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Abstract

A critical aspect of human social cognition is the capacity to predict both others' goals and the expected costs and benefits associated with the pursuit of those goals. Thus far, it is unclear whether any animals outside of the primate clade represent the efficiency of other's actions, or whether any animal outside of humans can use other actors' behavior to inform their inferences about unknown rewards. While it appears that nonhuman primates expect other agents to maximize their efficiency in obtaining a goal (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al., 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011), the phylogenetic distribution of the expectation that agents behave as rational utility maximizers has remained largely unexplored. This paper provides evidence suggesting that rhesus macaques (*Macaca mulatta*) may be able to infer the relative quality of unknown food rewards given only an agent's costs and actions by measuring their preferential approach behavior; though more research is needed to reify this hypothesis. Additionally, it is unknown whether any species outside of the primate clade represent others' efficiency. While this thesis provides clear findings that dogs (*Canis familiaris*) can discriminate between the motions of direct and indirect reaching behavior, it does not offer evidence that they distinguish them in terms of efficiency.

Keywords: rational utility maximization, naïve utility calculus, rational action principle, efficiency, rationality, rhesus macaque, canine

Expectations of Rational Utility Maximization by Other Agents in Rhesus Macaques (*Macaca mulatta*) and Domestic Canines (*Canis familiaris*)

Even over the course of a relatively uneventful day, we make countless conjectures about others' behavior. If we're trying to get from one floor to another, we expect others around us to take the up elevator to the upper floor and the down elevator to the lower one – even if not consciously aware of these expectations, we are still surprised if these expectations are broken. Additionally, we can use these expectations to make predictions about unknown properties. If we observe another person passing by one package to retrieve another one atop a ladder, we could reasonably infer that the first package was less desirable than the latter, even lacking any additional information about their contents. Humans possess complex representations of others' utility calculations – we represent their goals, the different actions they could take to satisfy these goals, and the relative costs and benefits associated with the outcomes of these actions. Given this information, we expect other agents to rationally choose amongst a set of means to maximize their expected utility – namely, the net sum of an agent's expected cost and benefits from a course of action. If an actor is rational, they should only undertake means that result in outcomes with net positive utility, and if there are multiple actions that satisfy that criterion, they should be expected to select the one with the largest positive utility.

For the purposes of this thesis, we will consider two functional classifications of these utility calculations – *efficiency assessments* and *utility judgments*. This is by no means to assert that these classifications form a comprehensive taxonomy of utility

calculations, nor that they represent a strict dichotomy. However, conceptualizing these decisions as ones where an individual can evaluate the given cost and benefit of an action to determine the net utility (utility judgement) or ones where an agent can select among several courses of action to achieve a set goal (efficiency assessment) will be useful in the domain of this thesis.

To decompose these categories further, I'll define utility judgments as judgments that take a course of action and its outcome and evaluate the net utility of its costs and benefits to determine if it is worth undertaking. Engaging in a behavior with a negative associated utility is irrational. For example, building a shed can have a positive utility depending on one's resources, but building a shed only to immediately burn it down is almost never rational as one accepts all of the costs to construct it with none of the associated benefits of a shed to offset them. Efficiency assessments, on the other hand, are judgments that take one set goal with one concomitant expected payoff, and select the least costly action among a set of means that will achieve that goal, given environmental constraints. For example, if one wishes to cross a room to exit a door, an efficiency assessment will return the straight path unless there is some obstacle in the way. All other paths have higher associated costs, rendering them inefficient. If an individual expects other agents to act as rational utility maximizers, they have the capacity to represent others utility judgments and efficiency assessments, and they expect them to only undertake actions that maximize efficiency and have a positive net utility.

To return to the prior examples, an individual traveling the incorrect way down an escalator violates our expectation that they make rational efficiency assessments

because, while escalators can satisfy the goal of getting to a lower floor, one requires much more effort, since one must walk against its movement. Since the cost to move down the escalator is greater, the reward of reaching the lower floor will offset that associated cost by less or fail to offset it entirely. Given that the net utility of an action is the sum of the cost it takes to achieve it and the benefit one gains from its outcome, walking down the escalator that requires more effort will have a higher cost associated with it than walking down the low-effort escalator. This will subsequently give that action a lower or even negative net utility, rendering it the inefficient option.

Additionally, we are able to infer the relative quality of the two packages because we represent the choice between them as a choice between two expected utilities. Given that the known cost for the package on the ground is less (one does not have to climb a ladder to retrieve it) than the one at the top of a ladder, its associated quality therefore also has to be less, or it would be the more rational selection. Stated another way, if we expect the agent to behave rationally, the expected desirability of the higher package would have to be greater to justify the greater cost of obtaining it to maximize utility.

While these utility representations are easy for adult humans to generate, it is unclear to what extent other agents share the expectation that agents act as rational utility maximizers. Humans as a species have uniquely created complex global societies, rich verbal languages, and a cumulative culture in which individuals and groups continually build upon the past innovations of others who may be vastly removed from them in time and space. All of these characteristics of humanity are the result of inherently social endeavors and have been facilitated by our social cognition. Investigating which aspects of our social cognition are unique (or if they are not wholly

unique, how they might differ in degree, expression, or emergent properties) may offer us an insight into what capacities have enabled our unique global impact. This exploration can also inform whether complex animal behaviors that are functionally similar to our own are also similar in their underlying cognitive representations and mechanisms.

To date, little work has explored how nonhuman animals represent the costs and benefits associated with other actors' actions. This far, much of that research has been conducted with nonhuman primates, as they are both near phylogenetic relatives – sharing a high overlap in both our genes and evolutionary history – and because many live in complex, hierarchical, multi-male, multi-female groups that impose some of the same social pressures that are inherent in navigating human groups. It appears that nonhuman primates can represent others' efficiency assessments and expect them to minimize their cost in achieving a goal given the constraints imposed by the environment. This is evidenced by the fact that nonhuman primates look longer at familiar, inefficient actions than at novel, efficient ones (Rochat et al., 2008; Uller, 2004); and they selectively neglect to imitate the inefficient actions of a demonstrator when there are clear environmental constraints imposing that inefficiency (Buttelmann et al., 2007; Buttelmann et al., 2008; Wood et al., 2007; Wood & Hauser, 2011).

However, it is unclear if, as in the ladder example, they can infer the relative desirability of unknown rewards given only another agent's actions. We know that five-year-old children can represent these sorts of utility judgments due to the fact that if they are provided with information about two of the following three – an agent's goals, costs, and actions – they can make productive inferences about the third (Bridgers et al.,

2016; Jara-Ettinger et al., 2015; Jara-Ettinger et al., 2016), but not anything of evolutionary history nor phylogenetic distribution of this ability. We know even less about rationality expectations in dogs as there is no literature on their ability to use another's behavior to inform their inferences about the relative quality of unknown rewards, and the literature regarding whether they expect others to minimize their cost in obtaining a goal given environmental constraints is mixed (Huber et al., 2012; Huber et al., 2014; Kaminski et al., 2011; Range et al., 2007; Tauzin et al., 2017). Their phylogenetic distance from humans, combined with their history of domestication (wherein they were often selectively bred to be increasingly attuned to humans' goals, constraints, and behaviors) makes them a particularly compelling species to explore the potential existence of representations of others' utility calculations outside of primates. The strengths of both species as research populations is worth expanding upon in more detail.

Rhesus macaques, as was mentioned briefly above, are a good population in which to explore these questions as they are a near phylogenetic relative, and they live in complex, hierarchical multi-male, multi-female groups, not too unlike our own. Evidence of utility judgments in rhesus macaques could suggest several possible explanations. One is that this ability is at least as evolutionarily old as the last common ancestor between rhesus macaques and humans, or approximately 28 million years old. Another is that the common social pressures of living in large, complex groups prompted the convergent evolution of this adaptation. Therefore, this line of research has the potential to shed light on the evolutionary history shared between our two

species or on the social conditions that enabled and promoted the dual emergence of the ability to represent others' utility calculations.

Domestic canines, on the other hand, also offer a good population to explore the extent of the ability to represent others' utility calculations. Wild canids also live in hierarchical social groups, so it may be the case these representations were sufficiently adaptive to have evolved ancestrally in dogs. Additionally, it is possible that this ability may have been selected for over the course of generations of domestication, as dogs were bred to be more and more attuned to human goals and behaviors. The current literature is divided as to whether domestic canines expect other agents to maximize their efficiency given environmental constraints (Huber et al., 2012; Huber et al., 2014; Kaminski et al., 2011; Range et al., 2007; Tauzin et al., 2017), with current literature either disputed or mixed in their findings.

Therefore, these populations could be of interest to explore the phylogenetic distribution of utility representations; and to potentially learn more about human evolutionary history, the social conditions that may promote these abilities, and the potential effect of domestication on this form of social cognition (though these latter possibilities would require more investigation to successfully parse).

Study 1: Representations of Other Agent's Utility Judgments in Rhesus Macaques (*Macaca mulatta*)

Literature Review

Infants.

Understanding of Action as Intentional/Goal-Oriented.

A critical prerequisite in the ability to represent the utility calculations of others is to first understand that the actions of other agents are accompanied by implicit goal-states. It is challenging to determine what a nonverbal infant may or may not comprehend about the tacit desires of a third-party, but by analyzing what surprises them (as measured by how long they spend looking at some unanticipated stimulus), we can explore what expectations these subjects hold about the minds of others. As it stands, there is an abundance of evidence demonstrating that human infants show surprise when others behave in ways that are inconsistent with possessing an underlying goal state (Baldwin et al., 2001; Behne, 2005; Brandone & Wellman, 2009; Carpenter et al., 1998; Csibra, 2008; Gergely et al., 2002; Hamlin et al., 2008; Leslie, 1994; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Meltzoff, 1995; Sommerville et al., 2005; Warneken & Tomasello, 2007; Woodward, 1998; Woodward, 1999).

Ten- to eleven-month-old infants look longer at videos where agents are paused mid-action than at videos where the video paused at goal-completion points (i.e. infants are surprised that an actor stopped mid-reach as opposed to at the point of grasping) (Baldwin et al., 2001). Infants can also infer the goal of an action even when it was unsuccessfully completed (Brandone & Wellman, 2009). Six-and-a-half-month-olds begin to attribute goals flexibly even in the absence of featural cues – understanding an animate box as intentional from its motion when it could actively adapt its approach behavior toward a target object (Csibra, 2008). When subjects of roughly the same age are habituated to an agent reaching for one of two objects, they look longer when the actor reaches to the second object in the original location (new object) than to the same object in a new location (new path), suggesting that they encode the goal of a behavior

and not just the action itself (Luo & Johnson, 2009). This same pattern has been demonstrated in infants ranging from twelve (Luo & Baillargeon, 2007), to five months of age (Woodward, 2009; Woodward, 1998), and even in infants as young as 3 months if they are first given the experience of directed reaching facilitated by Velcro gloves as they are yet too young for grasping (Sommerville et al., 2005). Therefore, the use of looking time measures has provided convergent lines of evidence suggesting that infants attribute implicit goals to the actions of others – they infer the intended goal of incomplete actions (Baldwin et al., 2001; Brandone & Wellman, 2009), and they use modulated goal-approach behavior as a metric for attributions of agency (Csibra, 2008), they expect agents to preferentially maintain consistent goals over consistent physical sequences of movement (Luo & Baillargeon, 2007; Luo & Johnson, 2009; Somerville et al., 2005; Woodward, 2009; Woodward, 1998).

In addition to analyzing infants' looking behavior, insight into their expectations of intentionality can be gleaned from their actions, particularly their imitation. At as young as 7 months, subjects selectively reproduce the goals of goal-oriented actions, even when incomplete; but do not imitate goal-ambiguous actions (Hamlin et al., 2008). By 1-1.5 years of age, infants imitate intentional actions over accidental ones (Carpenter et al., 1998), and reproduce the goals of failed actions (Metzloff, 1995). Additionally, when viewing an experimenter activating a light with their forehead, 14-month-olds will only faithfully imitate the action when there is no visible constraint on the experimenter's behavior; and will instead replicate just the outcome (using their hands) when the presenter is subject to some restriction that does not apply to the baby themselves. This indicates a sensitivity to goals and not just to actions (Gergely et al.,

2002). Infants at 9 months of age are also more patient with an actor who is unable to give them a toy than with one who is unwilling, suggesting a comprehension of intention (Behne et al., 2005).

Expectations of Efficiency.

The understanding that action is goal-directed does not allow one to make any productive inferences about *how* that action might be undertaken to accomplish its given goal. That said, if one expects another agent to maximize their efficiency by minimizing the costs incurred to obtain a goal, then one can begin to create certain expectations about how agents might behave in the pursuit of a goal. The principle of rational action is the framework for this expectation of efficiency, and it was developed by European psychologists, Gergely and Csibra. The principle of rational action states that agents will pursue their goals by the most efficient means available given the constraints of the environment.

In their seminal study exploring the potential existence of a rational action principle in human infants, twelve-month-old subjects were first habituated to an animated ball arcing over a wall to come to rest next to a second ball. Once subjects habituated, the wall was removed and infants saw the ball either continue to jump over an obstacle that was no longer present or move in a new, straight-line path to join the second ball. Gergely and Csibra found that infants looked longer at inefficient, familiar paths than at novel, efficient ones (Csibra et al., 1999; Csibra et al., 2003; Csibra & Gergely, 2007; Gergely & Csibra, 1997; Gergely & Csibra, 2003; Gergely et al. 1995). This work has been replicated using human agents and more everyday behavior. Infants look longer when an experimenter reaches for a target object underneath a cover

(inefficient) rather than in a container (efficient); or from an opening facing away from the agent (inefficient) instead of one facing the agent (efficient) (Scott & Baillargeon, 2013). Further work has built upon this body of research pertaining to infants' expectations of efficiency in other agents. For example, infants process biomechanically impossible events as goal-oriented if they are efficient (e.g. an arm reaching around several 90° angles at once) (Southgate et al., 2008). Additionally, at three months old, infants will look longer at inefficient reaches if given firsthand experience with directed reaching (Skerry et al., 2013).

Outside of expectations about efficiency in paths and in reaching, infants also demonstrate a sensitivity to efficiency in terms of selective imitation. When an experimenter demonstrates turning on a light with her forehead in conditions where her hands are either otherwise occupied (efficient) or free (inefficient), 14-month-old infants will faithfully imitate the action in the hands-free condition, but will reproduce only the goal in the hands-occupied condition (Gergely et al., 2002). Imitating the less efficient behavior only when there is no constraint to justify the action suggests a sensitivity to efficiency. By attaching an intentional significance to an inefficient behavior (i.e. by choosing to imitate it when there is no alternative justification for its inefficiency), it suggests that there was both an awareness of the most efficient means of pursuing that given goal and an expectation that the actor would take it. Whether this intentional significance is understood as some causally opaque, but necessary action or rather as some normative imperative is not important for this investigation; only that there apparently existed some expectation of efficiency and that the behavior being imitated violated that expectation.

However, some scholars have pushed back against Gergely et al.'s assertion that 14-month-old infants were showing rational imitation. Beisert et al., 2012 replicated Gergely et al.'s original methods, but with two new conditions to control for the novelty – and therefore the level of distraction – introduced by the blanket around the experimenter's upper body. Their claim was that the sudden occlusion of the experimenter's upper body by the blanket overwhelmed subjects' attention. Therefore, it was this distraction and *not* an appreciation of the actor's rationality that led to the drop in faithful imitation. When subjects were instead first familiarized to the presence of the blanket in the hands-occupied condition, rates of imitation increased. Conversely, if a blanket was introduced around the actor's shoulders during the demonstration in the hands-free condition, frequency of imitation then dropped. These findings certainly cast doubt on Gergely's claim that 14-month-old infants are attuned to the efficiency of an agent's actions, and that they adjust their imitation accordingly.

Overall, there seem to be several lines of converging evidence pointing to an early emerging expectation of efficiency in human infants. For one, babies in their first year of life dishabituate to familiar, inefficient behavior in the form of both path-movement and reaching. For another, slightly older infants may also selectively imitate the inefficient actions of a demonstrator when there are no visible constraints to justify them; though there was a failure to replicate this effect when controls for the familiarity of the blanket being used were incorporated.

Representations of Other Agents' Utility Judgments.

Early in this paper, an example was given where one could infer the relative quality of the unseen contents of two boxes when another agent undertook a

significantly greater cost to obtain one of them. This ability to represent the unseen utility judgments of others was termed the naïve utility calculus by Julien Jara-Ettinger (Jara-Ettinger et al., 2015; Jara-Ettinger et al., 2016). Under naïve utility calculus, one assumes that agents act as rational utility maximizers. Given knowledge of two of the three of the following – rewards, costs, and actions – one can infer the third. There’s a small collection of research demonstrating children’s ability to integrate actors’ costs (both objective and subjective) and rewards under overall utility. In one such study, Julian Jara-Ettinger and colleagues showed 5-year-olds can use information about an agent’s costs and actions to infer the relative subjective quality of two rewards to that agent. In the study, experimenters would show children that two different food items (crackers or cookies) were in two different locations (a high or a low shelf).

Experimenters would then tell children that a puppet retrieved one of the food items and ask what they thought the puppet’s preference was. (e.g. Children inferred that the puppet must have a preference from a retrieved food item from the high shelf, but not the low shelf, as retrieving an item from the high shelf was costlier (Jara-Ettinger et al., 2015; Jara-Ettinger et al., 2016). Further, given the chance to “teach” a confederate of the study how to use one of several new toys, children could integrate knowledge of another’s subjective costs and rewards for each given toy to choose to teach the one that would maximize the overall utility of that person (Bridgers et al., 2016).

Nonhuman Primates.

Understanding of Action as Intentional/Goal-oriented.

A significant amount of research has been invested in the exploration of infant and young children’s social cognition. This research has found that goal-representation

(Baldwin et al., 2001; Behne et al., 2005; Brandone & Wellman, 2009; Carpenter et al., 1998; Csibra, 2008; Gergely et al. 2002; Hamlin & Woodward, 2008; Leslie, 1994; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Meltzoff, 1995; Sommerville et al., 2005; Warneken & Tomasello, 2007; Woodward, 1998; Woodward, 1999) and expectations of efficiency (Beisert et al., 2012; Csibra et al., 2003; Csibra et al., 1999; Csibra & Gergely, 2007; Gergely & Csibra, 1997; Gergely & Csibra, 2000; Gergely & Csibra, 2003; Gergely et al., 1995; Scott & Baillargeon, 2013; Skerry et al., 2013; Southgate et al., 2008) come on-line within the first year of life, and that a naïve utility calculus is incorporated into children's representations of others at age five (Bridgers et al., 2016; Jara-Ettinger et al., 2015; Jara-Ettinger et al., 2016). These investigations sought to determine *when* typically-developing humans begin to represent other agents as rational utility maximizers, not *if* they ever came to do so. Given that neurotypical adults can represent the utility calculations of others, these capacities must arise at some point during development – it becomes a matter of at what age.

That said, while one can reasonably hold this assumption that infants and children will come to expect other actors to behave as rational utility maximizers over the course of ontogenetic development, the phylogenetic development and distribution of this expectation within the primate clade as a whole is less clear. Even though many primate species live in large social groups where the ability to track the goals and obstacles of conspecifics would intuitively seem adaptive, there is no corresponding basis on which to assume that nonhuman primates represent other actors' utility calculations without investigation. However, the current understanding of research suggests that nonhuman primates represent the implicit goals of an actor's behavior

(Barnes et al., 2008; Buttelmann et al., 2012; Call et al., 2005; Call et al., 2004; Call & Tomasello, 1998; Canteloup, 2017; Drayton & Santos, 2014; Drayton et al., 2016; Greenberg et al., 2010; Melis & Tomasello, 2013; Myowa-Yamakoshi & Matsuzawa, 2000; Phillips et al., 2009; Warneken et al., 2007; Warneken & Tomasello, 2006; Warneken & Tomasello, 2009; Yamamoto et al., 2009a; Yamamoto et al., 2009b; Yamamoto et al., 2012) and that they expect others to act efficiently (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al., 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011).

An important prerequisite is the ability to represent others as rational utility maximizers is the understanding that actors' behaviors are directed toward a final goal state, and this is an ability that appears to be represented in some species of New World monkeys (capuchins – Barnes et al., 2008; Drayton & Santos, 2014; Phillips et al., 2009), Old World Monkeys (tonkean macaques – Canteloup, 2017) and apes (orangutans & chimpanzees – Call & Tomasello, 1998; chimpanzees – Buttelmann et al., 2012; Call et al., 2005; Call et al., 2004; Greenberg et al., 2010; Myowa-Yamakoshi & Matsuzawa, 2000; Warneken et al., 2007; Warneken & Tomasello, 2006; Warneken & Tomasello, 2009; Yamamoto et al., 2009a; Yamamoto et al., 2009b; Yamamoto et al., 2012). One way to determine if nonhuman primates understand the intention behind an action is to assess if they can anticipate the goal of a failed effort. When an experimenter attempts to open a container using one of several different strategies, chimpanzees open the container using the strategy that was demonstrated to them significantly more often than any alternate strategy, even when the demonstrated action was unsuccessful (Myowa-Yamakoshi & Matsuzawa, 2000). This suggests that they are representing the

agent's goal and not just attending to their physical actions, as the actions are insufficient to produce the desired goal state. Chimpanzees further show sensitivity to the goal of an action by reproducing the end state of a conspecific's demonstrated action (accessing the contents of a tube) even though they fail to faithfully imitate their behavior (Call et al., 2005).

Results such as these could be attributed to apes' sensitivity to behavioral cues or stimulus enhancement as opposed to a richer representation of other agents' goals. However, when presented with identical behavior during a test phase (e.g. manipulating a box or standing up), chimpanzees and bonobos waited in the testing area longer when that behavior had been contextualized as instrumental to the subject receiving a food reward than when that behavior had been associated with no perceivable outcome (gorillas and orangutans remained in the testing area for a similar duration across both conditions) (Buttelmann et al., 2012). Capuchin monkeys showed no difference in latency to leave or time spent in the testing area (Drayton et al., 2016). Given that the agent's behavior was identical across trials, chimpanzees and bonobos could not have been relying on perceptual variation to discriminate between the test trials, and therefore were likely to have been representing the presenter's tacit goal.

Spontaneous helping also a useful metric for assessing goal sensitivity in nonhuman primates. In order to assist an agent in accomplishing a goal state, an individual must first be able to infer what that desired outcome may be. Capuchins retrieve out-of-reach objects for human experimenters (Barnes et al., 2008; Drayton & Santos, 2014), suggesting that they comprehend that the experimenter desires the object. Chimpanzees also retrieve out-of-reach objects for experimenters (Warneken et

al., 2007; Warneken & Tomasello, 2006; Warneken & Tomasello, 2009), in addition to helping conspecifics access food – both by opening an intervening door (Warneken et al., 2007; Warneken & Tomasello, 2009) and in a joint pulling task (Greenberg et al., 2010). Additionally, they will provide an instrumental tool to a conspecific that needs it to accomplish a goal (Yamamoto et al., 2009; Yamamoto et al., 2009b), even when they must select from a range of potential tools to do so (Yamamoto et al., 2012). This instrumental helping provides evidence for a representation of other actors' goal states in capuchins and chimpanzees.

Assessing whether or not subjects modify their behavior when presented with intentional as opposed to accidental behavior is also informative as to whether or not they perceive the goal of an action. If they regard mistaken action in the same way as deliberate behavior, then they are likely attending to the physical sequence of actions, rather than representing the desired outcome. Capuchins (Phillips et al., 2009), Tonkean macaques (Canteloup, 2017), and apes (Call et al., 2004; Call & Tomasello, 1998), representing a sampling of New World Monkey, Old World Monkey, and great apes, all appear to distinguish intentional, goal-directed actions from those that are accidental. When a demonstrator indicates two containers as the location of a single hidden food item – one intentionally and one accidentally – chimpanzees and orangutans preferentially select the container on which the actor purposefully placed a marker (Call & Tomasello, 1998). This suggests that they recognized that the intentional action was accompanied by an implicit goal of placing the marker, while the accidental behavior possessed no concomitant goal. Additionally, capuchins, Tonkean macaques, and chimpanzees will remain in a testing area for longer and direct more behaviors of

solicitation toward an agent who is unable to give them a food reward (due to clumsiness, a barrier, or distraction), whereas they are more likely to leave or express frustration when faced with an experimenter who is unwilling to offer them the same reward (*chimpanzees* – Call et al., 2004; *macaques* – Canteloup, 2017; *capuchins* – Phillips et al., 2009). These results suggest that at least some species of nonhuman primates represent the intended goal of an action, and not just its outcome.

Taken together, these results suggest that many nonhuman primates understand behavior as goal-oriented. Both monkeys and apes reproduce the intended end-state of an action, even when that action fails to achieve the desired outcome (Call et al., 2005; Myowa-Yamakoshi & Matsuzawa, 2000); they distinguish the distinct goals of identical behaviors based on temporally-distant contextual information (Buttelmann et al., 2012); they provide instrumental help in facilitating other's goals (Barnes et al., 2008; Drayton & Santos, 2014; Greenberg et al., 2010; Warneken et al., 2007; Warneken & Tomasello, 2006; Warneken & Tomasello, 2009; Yamamoto et al., 2009a; Yamamoto et al., 2009b; Yamamoto et al., 2012); and they discriminate between visually-similar accidental and intentional behavior, suggesting goal-sensitivity (Call et al., 2004; Canteloup, 2017; Phillips et al., 2009).

Expectations of Efficiency in Nonhuman Primates

As with human infants, there are also convergent lines of evidence for a principle of rational action in nonhuman primates using both looking time and selective imitation paradigms (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al., 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011). Two studies adapted the method of Gergely and Csibra's seminal work for use with infant chimpanzees (Uller, 2004) and

rhesus macaques (Rochat et al., 2008); using a human experimenter instead of an animated ball and reaching over a barrier instead of jumping over a wall in the case of the macaques. Like infants, chimpanzees and macaques looked longer at familiar, inefficient reaches (when the agent acted as though they were still reaching up an over a barrier that was no longer there) than at novel, efficient reaches (Rochat et al., 2008; Uller, 2004).

Beyond their original finding that, given knowledge of an agent's goal and constraints (or lack thereof), infants can infer the (most efficient) action that an actor is likely to take, Gergely and Csibra went on to investigate if, given knowledge of any two of the three (constraints, goals, and actions) infants could infer the third. They found that subjects were just as successful at goal- and constraint-inference as they were at action-inference. Similarly, cotton-top tamarins, rhesus macaques, and chimpanzees (representing a New World monkey, an Old World Monkey, and a great ape species) all demonstrate an ability to infer a goal from an actor's behavior and constraints; though the assumptions in this study hinged more on intentionality than on efficiency (Wood et al., 2007; Wood & Hauser, 2011). Chimpanzees also demonstrate the ability to selectively imitate. When a human demonstrator operates an apparatus inefficiently (with a foot, forehead, behind, etc.), chimpanzees are more likely to reproduce the inefficient action in the hands-free condition, and more likely to reproduce only the goal in the hands-occupied condition when the non-intuitive behaviors of the demonstrator are otherwise justified (Buttelmann et al., 2007).

Therefore, there appears to be evidence of a rational action principle in nonhuman primates, as they look longer at familiar, inefficient reaches than at novel,

efficient ones; and they selectively imitate ostensibly inefficient behavior when there is no constraint to justify it.

Experiment

In this study, subjects watched a presenter open and eat an unknown food item from two boxes. One of these boxes, the actor opens with ease, and the other they do so with great effort. After opening the boxes, the presenter leaves them opened on the ground, and the subject gets the chance to approach and investigate one of the two boxes for more of the unknown food reward (the boxes are set too far apart for the subject to inspect both simultaneously). Given that the lids have been removed from both boxes, the cost to access the contents of both is null for the subject, and their choice to approach one over the other should be based on the expected quality of the unknown food reward.

If rhesus macaques possess a naïve utility calculus, they should expect that a rational agent will only invest the effort in completing an action if the expected utility of that action is a net positive – i.e. if the expected value of the reward exceeds the expected cost. If subjects are indeed representing other actors' utility judgments, then this expectation should give them more information with which to make an inference about the relative quality of the unknown food reward in the high-cost box than the low-effort box. With the former, only a high-quality expected reward would justify the high effort invested by the actor. The latter is simply more ambiguous – a high value or a low value reward would offset the negligible cost of merely opening the lid. Therefore, given that subjects can only approach one box first, they should approach the high-cost box as they would infer there was a larger likelihood of that unknown food-reward being of

better value. If they fail to do so, it could suggest that rhesus macaques do not possess robust representations of other actors as rational utility maximizers.

Methods.

Subjects.

We tested 23 adult free-ranging rhesus macaques, *Macaca mulatta*, living on the island field site, Cayo Santiago; 35 others that were approached by experimenters were excluded from analysis due to interference or failure to approach. The site's population consists of 6 social groups totaling roughly 1700 individuals altogether. The island is maintained by the Caribbean Primate Research Center through the University of Puerto Rico. Purina monkey chow is provided at three feeding stations, along with ad libitum access to water at many more. Subjects also eat leaves, flowers, soil, and occasionally, food brought and eaten by humans at the field site (Flombaum & Santos, 2005; Santos et al., 2001). Cayo Santiago has housed a research population since 1938, with all subjects born on the island. Further, this population has successfully been tested on similar cognitive questions over the past 20 years (Flombaum & Santos, 2005; Santos et al., 2001). With daily researcher presence on the island, subjects are well-habituated to human presence. Subjects are identified through a unique combination of chest tattoos and ear notches.

Apparatus and Procedure.

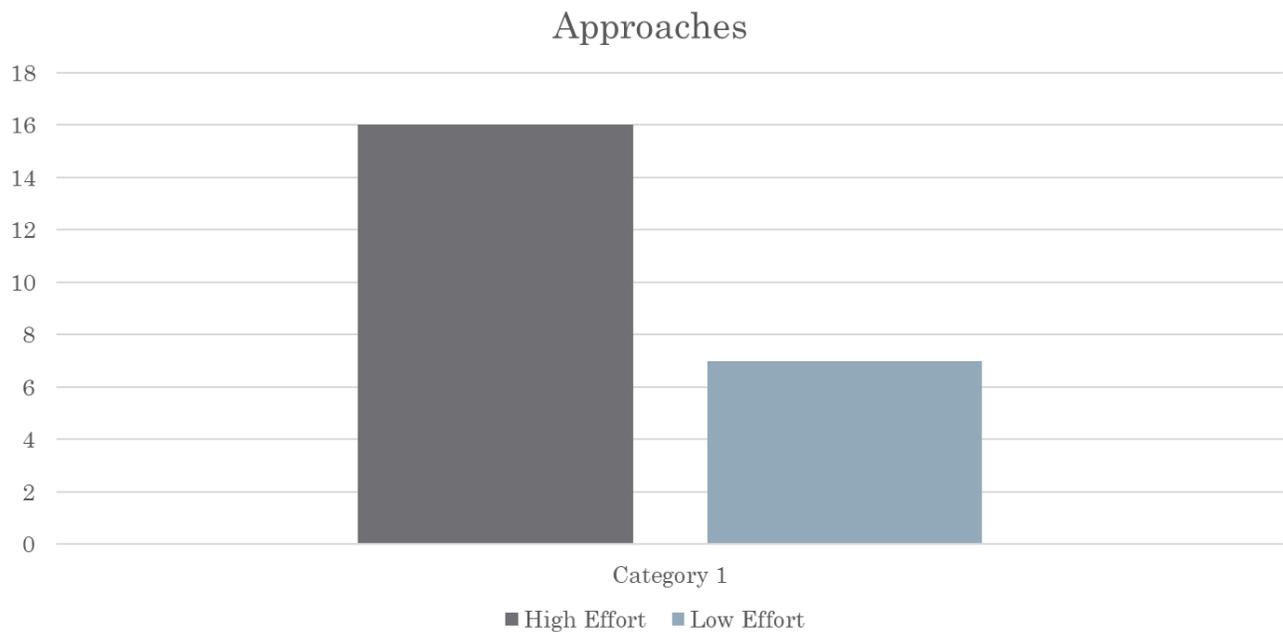
The study was carried out by an experimenter and a cameraperson. The experimenter interacted with the target objects in front of the subjects. The target objects were two plastic boxes (7.62 cm x 15.24 cm x 22.86 cm) with pink, plastic latch-

on lids and occluded with turquoise duct tape. When in use, both boxes were filled with leaves taken from the island that morning. The cameraperson filmed the interactions with a Panasonic HC-V180K Full HD Camcorder. The cameraperson also served as a timekeeper, verbally-instructing the experimenter when to shift attention between boxes.

As in prior studies (Flombaum & Santos, 2005; Santos et al., 2001), subjects were selected who were seated alone (without any other conspecifics in sight) and not currently feeding or grooming. The experimenter approached the subject from the front, holding the two boxes and assumed a kneeling position 2-3 m away, while the cameraperson filmed from 4-5 m behind the subject. When in place, the experimenter began the presentation by drawing the subject's attention ("Monkey" accompanied by tapping the boxes together). If the subject looked away at any point during the presentation, the cameraperson would inform the experimenter ("Not looking"), and they would regain the subject's attention. The experimenter would then place both boxes on the ground and pick up the one sitting on either the right or the left (counter-balanced across trials). For the following 10 seconds, the experimenter strained to open the high-cost box, prying at the lid and yanking on the handle. When the ten seconds had elapsed, the cameraperson cued the experimenter to move on ("Stop), and the experimenter removed the lid, set it behind them, and pretended to eat something from inside the box. They then set the box down in front of them and picked up the remaining box. This time, they unlatched the lid immediately, and pretended to eat something from within the box. The order in which the experimenter first interacted with the high-cost or the low-effort box was randomized across trials. When finished, the

experimenter lifted both boxes, set them 1 m apart on the ground (“Now”), and walked 4-5 m away with the lids, facing away from the subject. Subjects then had 30 s to approach one of the two boxes. The cameraperson determined the first box touched as the subject's choice, and ended the trial. Subjects who failed to approach within 30 s were omitted from analysis. We also excluded trials in which another individual interfered with the subject's approach. Video recordings of all sessions were digitized and scored offline by the author and a blind coder.

Results & Discussion



Subjects reliably preferred to approach the high-cost box (binomial probability: $p = 0.046$; $N = 16/23$). Success on this task requires that subjects understand that a rational actor will only undertake an action that has a positive net utility, and should reject a course of action where the expected cost exceeds the expected benefit. This result provides early and tentative support for the possibility that nonhuman primates

make use of a naïve utility calculus when judging the behavior of others, and can infer the relative quality of an unknown reward from the costs undertaken by other agents alone.

This study represents the first investigation into whether a nonhuman primate represents the utility judgments of others. Though much further research is required to determine if a naïve utility calculus is truly a component of rhesus macaques' understanding of other actors, these results provide tentative support for the hypothesis that they can use the behavior (i.e. effort) of others, integrated with an understanding that agents act as rational utility maximizers, to infer the relative quality of unknown rewards. This work expands upon prior work that establishes that nonhuman primates generally – and rhesus macaques specifically – apply the rational action principle to the behavior of other actors, expecting them to choose the least costly means available to obtain a given goal (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al.; 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011).

Though they are hesitant to come too close to humans, the macaques on Cayo Santiago are interested in the food that researchers occasionally carry with them; and in certain situations, they are motivated to attempt to take it (Flombaum & Santos, 2005; Santos et al., 2001). Subjects were given the opportunity to search one of two boxes for an unknown food reward, and we predicted that they would explore the contents of the box that a human presenter had invested more effort in opening. Given that subjects didn't know the value of either food reward (as, in fact, there were none), we reasoned that they could use the different costs that the actor had accepted to infer which box was more likely to contain a high-reward food item through a naïve utility calculus

representation. Only a high expected value would offset the observed high-investment behavior, whereas a reward of almost any value would justify the low cost of removing a lid.

Limitations & Future Directions.

One limitation in the interpretive power of this data is the fact that the methodology employed necessitates a restricted subject pool. We used a preferential approach method to gauge subjects' choices. This method necessitates that there be no conspecifics in the vicinity who may displace the subject or influence their side selection (e.g. a subordinate subject choosing one box because it is farther from a nearby dominant individual rather than because they believe it contains a higher value food reward). Rhesus macaques are strongly-hierarchical, and rank considerations play a strong role in individual behavior when in the presence of conspecifics. Additionally, females and dominant males spend nearly all of their time in the midst of their matriline and wider social group. Therefore, the overwhelming majority of subjects tested in this experiment were low-ranking or extra group males (1 of the 23 monkeys tested was female). Further, this method precludes the option of investigating the potential developmental trajectory of utility judgments in rhesus macaques, as young monkeys are nearly always with their mothers and matrilines. Understandably, this results in a subject pool that is far from representative of the wider rhesus macaque population.

Further, the explanatory power of these data is significantly hindered by notable lack of follow-up experiments to both replicate and verify that this finding is truly an indication that rhesus macaques are representing the utility judgments of other actors. For one, while significant ($p = .046$), this finding was relatively weak, and it would be

ideal to replicate these results with a larger sample size. This would be challenging, however, due to the fact that there is a limited number of low-ranking and extra-group individuals, and that 23 of them have already been tested (many of these were reemerging as repeat trials near the end), this could prove challenging.

In the interest of ensuring that this finding indicates that rhesus macaques integrate a naïve utility calculus into their representation of others behavior, a clarifying follow-up needs to be run. For one, our finding could be attributable to the fact that the experimenter attended to one of the boxes for longer. Simply due to the fact that the presenter handled one of the boxes momentarily and the other for 10 s, subjects may preferentially approach the high-cost box as a result of stimulus enhancement. Therefore, a future study could control for this possibility by having the agent hold or manipulate the low-cost box for 10 s and strenuously open the high-cost box for an equal amount of time. If subjects continued to preferentially approach the high-cost box, this would more strongly suggest that rhesus macaques represent the utility judgments of other agents, and aren't merely choosing the box to which the experimenter spent more time attending.

Unfortunately, neither the replication nor follow-up study were possible due to Hurricane Maria, a category 4 storm that made landfall on September 20. The storm devastated the island, the Caribbean Primate Research Center, and the surrounding community, Punta Santiago. Following the storm, research on the island was severely restricted and these experiments were not possible. Given this unforeseen disruption in my thesis research, I decided to open a related line of investigation in domestic canines – namely whether dogs expect actors to behave efficiently.

Study 2: The Principle of Rational Action in Domestic Canines

In 1999, Gergely & Csibra defined the principle of rational action as the expectation that agents will take the most justifiable action toward a goal state available given the constraints of the environment (Csibra et al., 1999). We as humans use this heuristic when assessing the efficiency of other actors constantly. When crossing traffic, we predicate our movements on the assumption that drivers will take a straight-line path to the next intersection, and will not, for example, veer off onto the sidewalk. An efficiency assessment will affix a judgement of rationality to an action on the basis of compliance with the rational action principle. For example, if an agent wanted to get directly from Michigan to New York, first going to Georgia would violate the rational action principle and thus be regarded as inefficient because that actor failed to maximize their utility given their goal state and the environment. In addition to adults, it appears that young human infants (Beisert et al., 2012; Csibra et al., 2003; Csibra et al. 1999; Csibra & Gergely, 2007; Gergely & Csibra, 1997; Gergely & Csibra, 2003; Gergely et al., 1995; Scott & Baillargeon, 2013; Skerry et al., 2013; Southgate et al., 2008) and nonhuman primates (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al.; 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011) also relate others' actions through the principle of rational action. However, it is unclear as to whether this expectation of efficiency exists outside of the primate clade; and it is possible that it emerged there uniquely.

Domestic canines (*Canis familiaris*) are promising candidates in this search for the rational action principle outside of primates because they live in complex social

groups and they have undergone the process of domestication. Wild canids live in hierarchical social groups – these efficiency assessments may have been sufficiently adaptive in predicting the behavior of conspecifics to have developed ancestrally for dogs. However, if present, this expectation of efficiency could have arisen over the course of domestication as subsequent generations were bred to be more and more closely attuned to human goals and behavior. While the question of domestic canines' expectation of efficiency has been investigated (Huber et al., 2012; Huber et al., 2014; Kaminski et al., 2011; Range et al., 2007; Tausin et al., 2017), the results thus far have been mixed, with positive findings that are either qualified or contested.

Literature Review

Of the existing literature which touches on a sensitivity to behavioral efficiency in dogs, published findings display either mixed results (in the case of selective imitation) or negative results (in the case of attention to path efficiency). Following a demonstration by a conspecific, there is some evidence that dogs will selectively imitate seemingly inefficient actions when there are no environmental constraints imposing that behavior (Huber et al., 2014). After observing a demonstrator dog pull a handle to release a treat with its paw (an inefficient action), subjects were more likely to use their mouths to reproduce the goal (efficient action) when the demonstrator's mouth was occupied by a ball, and more likely to faithfully imitate when the demonstrator's mouth was otherwise unoccupied (Range et al., 2007). That being said, this result was thrown into question when it failed to replicate after controlling for the effect of the ball's presence on subjects' likelihood to use their mouths (either by distracting them from the demonstration or by priming them to grasp with their mouths) (Kaminski et al., 2011).

However, the validity of the replication paper was subsequently challenged by the original authors due to methodological critiques (e.g. Kaminski et al. coded using first successful action instead of first action, etc.) (Huber et al., 2012). I would add the additional criticism to the Range et al., 2007 finding that the dogs included were sampled primarily from a subject pool of agility, rescue, service, and dancing dogs which limits the capacity for these findings to be generalized to the wider, more representative population of companion dogs. Thus, the literature on canine selective imitation is a muddied one.

More directly related to efficiency sensitivity is a 2017 Tausin et al. study which investigated whether dogs could use modulated approach behavior and path efficiency to attribute goal-directed agency to self-propelled objects. It found that when given a choice between two such objects, both human toddlers and companion dogs preferentially approached the one that demonstrated distal sensitivity, as opposed to one that was frequently bumping into objects as it moved around. They deemed this an attribution of navigational agency. However, when provided the chance to approach either a self-propelled object that demonstrated distal sensitivity or one with the additional ability to modulate its approach behavior to take direct paths toward its goal, dogs' choice was at chance while human toddlers preferentially chose the latter object. The authors deemed this goal-directed agency attribution, and the canine subjects in this study seemed to lack it. Therefore, the most recent literature appears to indicate a lack of sensitivity to path-efficiency in dogs.

As can be understood from the body of literature on infants' understanding of others as rational agents, children come to expect that other actors behave in a

maximally efficiently manner given environmental constraints within the first year of life. It similarly appears as though nonhuman primates have comparable expectations of efficiency, though the literature for this group is much sparser. Given the mixed findings as to whether dogs are attending to the relative efficiency of conspecific behavior in selective imitation tasks and their failure to preferentially choose path-efficient agents over inefficient ones, there does not at this time appear to be robust empirical support for an expectation of efficiency in dogs.

Experiment

This experiment is not a replication of Study 1 with dogs instead of primates. In contrast to the above experiment conducted with rhesus macaques, this study explores the existence of an expectation of efficiency and not the ability to infer the desirability of an unknown reward given knowledge of an actor's obstacles and behaviors. Before investigating the presence of a naïve utility calculus in rhesus macaques' interpretation of other agents' behavior, it was already established that they possessed a rational action principle (Rochat et al., 2008) that functioned similarly to human infants (Gergely et al., 1995; Gergely & Csibra, 2003) and infant chimpanzees (Uller, 2004). One can imagine that – 1) assuming the presence of never-seen rewards, then 2) inferring disparity in desirability between them, and 3) integrating that information into one's own utility calculation – is a more cognitively demanding task than 1) having visual access to an actor, their goal, and their constraints and 2) making a judgement as to what the most efficient means of navigating the constraints to reach the target object may be. Therefore, before investigating the potential existence of a more complex mental

capacity such as a naïve utility calculus, we sought to first establish the presence or absence of comparatively simpler efficiency assessments in dogs.

This experiment operates as a conceptual replication of Gergely & Csibra's seminal work in investigating the presence of a rational action principle in human infants (Gergely et al., 1995; Gergely & Csibra, 2003) and of Uller's extension of that investigation into infant chimpanzees (Uller, 2004). Moreover, it is also a methodological replication of Rochat's work exploring the rational action principle in rhesus macaques (Rochat et al., 2008) – wherein, instead of having an animated agent navigating over a wall, a live human experimenter reaches up and over a barrier. In this paradigm, subjects are habituated to an actor reaching over an obstacle to grasp a target object. Then that barrier is removed, and the presenter either grasps the target object directly or continues to reach up and over, in the same manner as when the obstacle is present. Subjects' looking behavior is recorded to see if they look longer at either of the two test stimuli. If dogs possess an expectation of efficiency, they should look longer at a familiar, inefficient reach that no longer makes rational sense in the constraint-free context than at a novel, efficient reach that minimizes the agent's cost and maximizes expected utility. A control condition is also run where the agent irrationally reaches up and over to grasp the target object in the absence of a barrier, not just for one of the test trials, but for all of the familiarizations as well.

Methods.

Subjects.

We tested 24 companion dogs (12 female), *Canis familiaris*, varying in breed and age, at the Canine Cognition Center at Yale University; 2 of which were excluded from

analysis due to the subject moving out of frame or failing to look at the start of a stimulus. All subjects lived as fulltime household pets, and their guardians volunteered them for participation through an online system. In order to qualify as a subject, dogs had to be up-to-date on vaccinations, have had no history of aggression, and be at least 6 months of age. Any dog that had participated in pilot studies was excluded from the subject pool. Additionally, all participants had visited the Canine Cognition Center at least once prior to testing, and informed consent was given by the guardians on the day of testing in order to proceed with the experiment. Participants were compensated with a certificate at the end of the session.

Apparatus & Procedure.

A within-subjects paradigm was used with half of subjects ($N = 11$) participating in the experimental condition and half in the control condition. Subjects were tested in a familiar room (3.5m x 3.15m) at the Canine Cognition Center. The guardian was seated in a chair centered on the far wall of the room, with their dog seated in front of them, on-leash, facing the presentation area. Two experimenters conducted each session – the facilitator and the presenter. Once the subject was in the room, the facilitator led them through a warm-up to expose them to a clear, rectangular, plastic bucket (24.23 cm x 10.07 cm x 33.02 cm) used in the experimental condition (though to keep sessions consistent, all subjects went through the warm-up). Dogs were given 15 s to explore the bucket laid on its long side and 15 s laid on its short side in the hope that this would solidify the fact that it was a solid barrier despite its transparency. The facilitator would tap the bucket to promote engagement if the subject failed to investigate on its own.

The facilitator then moved to stand at the far side of the presentation area from the door, facing the wall, with their back to the subject. The testing area was centered on the nearest perpendicular wall to the door (directly across from the subject), and consisted of a white foam core pedestal (.31 m x .31m x .91 m), flanked by a tripod mounted GoPro and a black stool (45 cm tall). The stool was placed on the side of the pedestal nearest the door and a small, opaque, black bucket (15.75 cm diameter x 20 cm height) sat next to it.

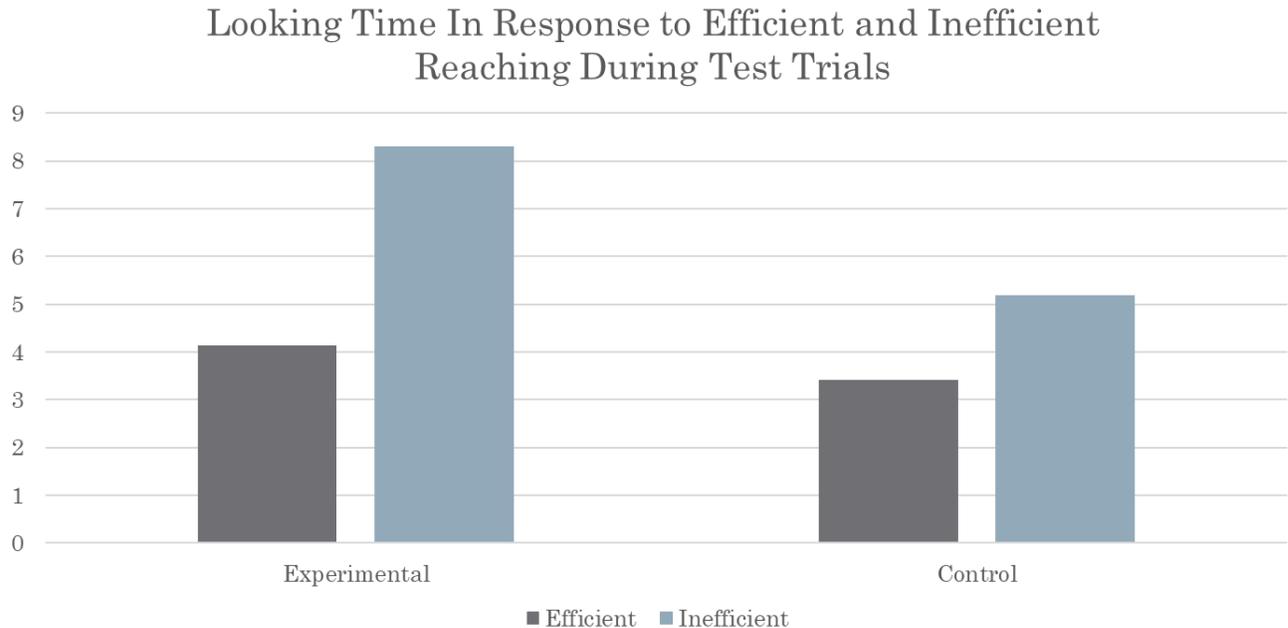
At this point, the presenter entered the room and took a seat on the stool, leaning forward to greet the dog. While the presenter was bent forward, the facilitator placed a red X-Large Kong® toy (12.7 cm) into the bucket behind the presenter's line of sight. The presenter then turned toward the pedestal and made a surprised vocalization at the sight of the toy ("Ooh!"), and reached up and over the edge of the bucket to grasp it. Once the presenter made contact with the target object, they froze in that position for 10 seconds, during which the subject's looking behavior was later coded offline. After the 10 seconds had elapsed, the presenter withdrew their arm from the bucket, with the target object in hand; turning away from the pedestal to study the toy. When the presenter had their back to the bucket, the facilitator placed another identical Kong® toy in the bucket. After placing the original toy into the opaque bucket next to the stool, the presenter turned back toward the pedestal, saw the new target object, and made the same interested vocalization ("Ooh!"). The process was then repeated for a total of three familiarization trials. The subjects were thus familiarized to the presenter reaching in a curvilinear motion up and over the barrier to grasp the toy. The familiarization trials for the control condition were identical in their action sequence (i.e. reach up and over in a

curvilinear trajectory, grasp, freeze, and withdraw), but differed in that the bucket was placed on the floor to the side of the presentation area after the warm-up and did not stand as a barrier between the presenter and the target object that constrained the reach.

After the three familiarization trials, the experiment proceeded directly into the two experimental trials. In the experimental condition, the facilitator removed the bucket from the pedestal and placed it on the floor to the side of the presentation area. In the control condition, the bucket remained unmoved in that same position. The experimental trials were identical across both conditions. The procedure of the two experimental trials was the same as in the familiarization trials (i.e. place target object while presenter is turned away, presenter pivots and sees it, vocalizes, reaches, grasps, and freezes); differing only in that one of the reaches was direct, while the other remained indirect and curvilinear. This direct reach followed a straight-line trajectory; and while it was a novel action, it was congruent with the rational action principle because the presenter selected the most efficient means possible to achieve their goal given (absent) environmental constraints (i.e. they maximized their expected utility by minimizing the effort taken to reach their goal). The indirect reach, on the other hand, maintained the curvilinear motion of the familiarization trials; however, while it was familiar, it was incongruent with the rational action principle because it failed to maximize the presenter's expected utility (i.e. with the constraint of the bucket no longer present, continuing to reach up and over was accompanied by a greater cost than was necessary to reach the goal and became an inefficient course of action). The order in

which subjects were exposed to the direct and indirect reaches during the test trials was counterbalanced across subjects.

Results & Discussion



A two-way ANOVA was conducted to compare the main effects of condition (i.e. whether the subject was familiarized to the agent reaching rationally up and over a barrier or irrationally up and over open air) and the efficiency of a reach (i.e. whether it was direct or indirect) during a given test trial, as well as the interaction between these two variables on subjects' looking time. The two main effects were significant at the .05 significance level, but the interaction was not. The main effect for condition yielded an F ratio of $F(1, 20) = 5.36, p = .026$, indicating a significant difference between looking time for subjects in the experimental ($M = 6.22, SD = 3.23$) and control conditions ($M = 4.30, SD 3.07$). Subjects who were familiarized to an actor rationally reaching over a barrier looked longer during test trials than those who were familiarized to an actor

reaching irrationally in the absence of a barrier. The main effect for reach efficiency yielded an F ratio of $F(1, 20) = 12.64, p = .001$, indicating a highly significant difference between looking time when subjects saw either efficient ($M = 3.78, SD = 2.71$) or inefficient reaches ($M = 6.74, SD = 3.15$). When subjects saw the presenter reach inefficiently, they looked highly significantly longer during test trials than when the experimenter reached efficiently for their goal. The interaction was not significant $F(1,20) = 2.08, p = .157$.

From these findings, one can reasonably conclude that subjects discriminated between the efficient and inefficient reaching motion, and that they look longer at the latter. However, given these results, one cannot strongly claim that this increased looking time was due to the violation of an expectation of efficiency in dogs because the interaction between condition and efficiency was insignificant. Given that the interaction was relatively near-significant ($p = .157$), it could be the case that dogs do interpret the actions of other actors in accordance with a principle of rational action, but that the power of this study, with a sample size of 22, was insufficient to detect it. However, it could also be the case that dogs possess no expectation of efficiency, and that they look longer at the inefficient reach because curvilinear motions are more visually interesting than straight-path ones or because humans, whom they are exposed to on a daily basis, are statistically less likely to reach in a curvilinear motion than a straight-line path, and they look longer at the less common behavior.

Limitations & Future Directions.

There are a number of limitations present in this study. For one, as mentioned above this experiment has a small sample size ($N = 22$), which limits the power of

analyses run on its data. The smaller the pool of subjects, the greater the risk of noise interfering with the sample to produce spurious effects or mask genuine ones. It is possible that the evidence of dogs' expectation of efficiency in this context is minimal enough that examining the looking behavior of 22 individuals is not enough to detect it. Due to the fact that the interaction between condition and reach-efficiency was relatively near significant ($p = .157$), it would be beneficial to collect roughly double the number of subjects on this same procedure. Additionally, the fact that subjects looked longer at the curvilinear reach regardless of condition could be attributable to that motion being more visually interesting or less common than a straight reach in dogs' day to day experience. These issues could be addressed by re-implementing these methods with stimuli that are equally appealing and equally common (or equally uncommon).

General Discussion

This paper examines sensitivity to the goals, obstacles, and behavior of others in two nonhuman animal species. In Study 1, we found positive initial indications that rhesus macaques possess a Naïve Utility Calculus and can infer the relative value of an unknown food reward given only the costs and actions of another actor – they selectively approach a box which an actor accepted a higher cost to open than one in which they invested minimal effort to access. However, the veracity of this claim is minimal without further testing to eliminate the possibility that subjects preferentially selected the high-cost box merely because the presenter attended to it for longer than the low-cost alternative. If it were to be more robustly demonstrated that rhesus macaques can use the behavior of other agents to make assumptions about ambiguous rewards, it would suggest that they can represent the utility judgments of others and

possess an expectation of rationality. This would raise the implication that nonhuman primates also represent the behavior of other agents as the outcome of cost-benefit calculations. If so, it may be the case that this ability arose ancestrally to the last common ancestor shared between our two species or that it arose independently in rhesus macaques as a result of shared social pressures. These findings also present the first tentative results indicating an intraspecies ability to use the costs and actions of another actor to infer the relative desirability of an unknown reward.

In contrast to the results found with rhesus macaques, the findings of our study with companion dogs did not support the hypothesis that they represent the utility calculations of others. Subjects did not look longer when an actor made a familiar, inefficient reach than a novel, efficient one. Therefore, this capacity may be restricted to the primate clade, though defining the boundaries of this distribution would require further exploration. Moreover, though domestication increases dogs' sensitivity to human social cues, these results do not appear to indicate that it improves their sensitivity to humans' constraints and behaviors.

These findings expand upon the existing literature – both moving the naïve utility calculus beyond children and helping to clarify the mixed findings on efficiency assessments in dogs. Prior to this research, it was known that nonhuman primates appear to comprehend the behavior of other agents as intentional and goal-oriented (Barnes et al., 2008; Buttelmann et al., 2012; Call et al., 2005; Call et al., 2005; Call & Tomasello, 1998; Canteloup & Meunier, 2017; Drayton & Santos, 2014; Drayton et al., 2016; Greenberg et al., 2010; Myowa-Yamakoshu & Matsuzawa, 2000; Phillips et al., 2009; Tomasello et al., 2005; Warneken et al., 2007; Warneken & Tomasello, 2006;

Warneken & Tomasello, 2009; Yamamoto et al., 2009; Yamamoto et al., 2012) and that they appear to represent others' behavior in terms of what is maximally-efficient given their goals and environmental constraints (Buttelmann et al., 2007; Buttelmann et al., 2008; Rochat et al., 2008; Uller, 2004; Wood et al., 2007; Wood & Hauser, 2011). That being said, it was previously unknown whether any nonhuman primate species could go beyond this to 1) infer the presence of unseen rewards to motivate an actor's actions 2) represent an agent's costs and behaviors in cases more complicated than point A to B movement with physical barrier constraints and 3) assume the likelihood that one of those unknown rewards is of a better quality compared to the other using only their knowledge of the actor's goals (inferred), actions, and costs (inferred). Additionally, the literature concerning these capacities (i.e. concerning a naïve utility calculus) was thus far both limited in scope and restricted to children (Bridgers et al., 2016; Jara-Ettinger et al., 2015; Jara-Ettinger et al., 2016). These findings offers tentative indications that rhesus macaques may represent other actors' utility judgments; expanding the research on nonhuman primate's utility calculations to more complex representations and moving research on a naïve utility calculus beyond humans.

This research also helps to clarify the mixed literature concerning whether dogs represent the utility calculations of others. Selective imitation offers a promising window into this question, as individuals who selectively imitate must overcome automatic copying tendencies, represent the goals, and not just the behavior, of an agent, and possess a notion of what action is auxiliary or inefficient in achieving those goals when imitating themselves. Unfortunately, the literature surrounding dogs' capacity for selective imitation is a muddled one. Friederike Range and collaborators

reported that dogs would faithfully imitate a demonstrator dog in using their paw (inefficient) to pull a lever for treats when the demonstrator's mouth (efficient) was occupied, but not when holding a tennis ball (justifying the inefficient paw use) (Range et al., 2007; Huber et al., 2014). That said, these results were called into question when a replication controlling for the presence of the ball failed to reproduce these findings (Kaminski et al., 2011). Subsequently, this response came under scrutiny itself for methodological critiques (Huber et al., 2012).

Moreover, when researchers investigated dog's preference for animate agents that moved with either navigational efficiency (avoiding bumping into obstacles) or navigational and goal-efficiency (modulating approach behavior toward a target goal). They found that dogs preferentially approached agents demonstrating navigational efficiency over no efficiency, but did not discriminate between agents that were navigationally efficient alone and those that were additionally goal-efficient. This suggests that dogs do not possess rich representations of other actors' utility calculations (Tauzin et al., 2017).

Into this divided literature, our results present evidence that dogs do not look longer when an experimenter takes a familiar, inefficient action than when they take a novel, efficient one; suggesting that they do not apply a rational action principle in representing the actions of other agents. These findings align with those of (Kaminski et al., 2011 & Tauzin et al., 2017) in that domesticated canines do not appear to represent the efficiency assessments of other agents.

Therefore, this thesis offers a limited foray into assessing the presence of a naïve utility calculus in rhesus macaques and a point of clarity into the debate concerning

whether dogs possess a rational action principle. The ability to represent others as rational utility maximizers is a nuanced means to comprehend and predict the behavior of others, and its distribution outside of humans is of great interest in understanding the social cognition of animals.

Author Contribution

Laurie Santos played a large role in the design of the studies presented in this senior thesis. Angie Johnston helped to interpret the results of the statistical tests used in interpreting the data in this research. Both Laurie Santos and Alyssa Arre offered guidance in the writing and organization of this senior thesis.

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