Criteria for Object Individuation and Numerical Identity in Infants and Adults: The *Object*-first Hypothesis

by

Fei Xu

A.B., Cognitive Science
Smith College
(1991)

Submitted to the Department of Brain and Cognitive Sciences in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

at the
Massachusetts Institute of Technology
September, 1995

Signature of Author ____________________
Fei Xu
Department of Brain and Cognitive Sciences
June 26, 1995

Certified by ____________________
Susan Carey
Professor, Brain and Cognitive Sciences
Thesis Advisor

Accepted by ____________________
Professor Gerald E. Schneider
Chair, Department Graduate Committee
Department of Brain and Cognitive Sciences

Criteria for Object Individuation and Numerical Identity in Infants and Adults: The *Object*-first Hypothesis

Fei Xu

Submitted to the Department of Brain and Cognitive Sciences in June, 1995 in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

Abstract

Philosophers of language have proposed that a class of concepts dubbed "sortals" underpins the logical functions of natural language count nouns. A sortal is a concept that provides principles of individuation (telling where one ends and another begins) and numerical identity (establishing whether something is the same one as one encountered at some other time). A sortal is akin to the common usage of the word "kind." Other grammatical categories such as adjectives or verbs do not fulfill these logical functions.

Different sortals dictate different conditions on individuation and identity. At the most general level is a sortal *physical object* , for which spatiotemporal criteria provide the sole conditions for individuation and identity. For example, one object cannot be at two places at the same time. More specific sortals, such as *dog* or *table*, rely on spatiotemporal as well as object kind information to provide criteria for individuation and identity. For example, upon seeing a dog in a room at time 1 and a table in the same room at time 2, people infer that there are two numerically distinct entities even in the absence of clear spatiotemporal information.

Results are presented from two series of experiments employing the visual-preference-for-violation-of-expectancy paradigm which suggest that at 10 months infants use spatiotemporal information but not object kind information for object individuation and identity. By 12 months, infants are able to use object kind information to do so. Hence the *Object*-first hypothesis: Early on infants may represent one sortal concept, *physical object*, and more specific sortals such as *dog* and *table* are acquired later in the first year of life. Preliminary evidence also suggests that the construction of specific sortals may affect the process of acquiring count nouns that name these sortals.

Furthermore, contrary to the philosophical literature, empirical and theoretical arguments are provided suggesting that even for adults, *physical object* functions as a sortal concept. Although adults conceptualize the world in terms of specific sortals, the sortal *physical object* nonetheless plays a role in our understanding of novel objects and metamorphoses.

Thesis Supervisor: Dr. Susan Carey
Title: Professor of Brain and Cognitive Sciences

Acknowledgments

I have truly enjoyed my graduate years at MIT. For four years of tremendous intellectual and personal growth, I am grateful to the following people.

First and foremost, my mentor and thesis advisor Susan Carey, who has been a constant source of inspiration and a wonderful role model. I am extremely lucky to have worked closely with her on a set of conceptual issues that have generated much interest in the field. Her insights into just about any domain of cognitive science, her deep intellectualism, her support, encouragement, and friendship, her high standards on matters theoretical and methodological, her willingness to share credit with students, and her talent as a teacher have given me much to strive for in my own career. Her philosophy of what science is about is clearly exemplified by her response to criticisms from a former student, "I don't mind being criticized, as long as they spell my name right" -- I shall always keep in mind this attitude towards one's intellectual opponents.

I would like to thank other members of my thesis committee: Steven Pinker, Molly Potter, Renée Baillargeon, and the unofficial member, Elizabeth Spelke.

Steve and I have worked on two projects together and it was he who first inspired me to come to MIT. Working with him has been intellectually challenging and I have learned much from his clear thinking, his theoretical and methodological rigor, and his eye towards details of argumentation as well as presentation.

Molly Potter has always provided constructive criticisms and support throughout my years at MIT.

Renée Baillargeon has kept me on my toes by disagreeing with my claims but at the same time being intensely interested in the work.

Elizabeth Spelke's insightful comments on the thesis and her interest in the work have been a source of inspiration and encouragement. Discussions with her have been terrific fun and I look forward to more of them in the future.

Special thanks to John Macnamara for writing his 1987 book which successfully bridged philosophy of language and cognitive science, and inspired this research. John Macnamara, Eli Hirsch, and especially Robert Stalnaker have helped me keep my foot firm on philosophical ground. Bob's tutorials on Wiggins' fascinating but opaque book on numerical identity have considerably shaped my thinking regarding the philosophical issues in Chapter 1.

Thanks to my undergraduate advisor and my dear friend Jill de Villiers -- for first introducing me to the excitement of cognitive science, for getting up at 5 a.m. to come to my first BU language conference talk, for inviting me back to Smith as a colloquium speaker, and for being a constant source of inspiration, support and encouragement.

I will miss the E10 lounge, where I learned much from my fellow graduate students and friends. Discussions with John J. Kim, Sandeep Prasada, Gary Marcus, Cristina Sorrentino, Gavin Huntley-Fenner, Suzie Johnson, Neal Pearlmutter, David Poeppel, Josh Tenenbaum, Flip Sabes, Sergey Avrutin, Kevin Broihier, Daphne Bavelier, Marvin Chun, William Snyder, Adee Matan, Annie Senghas, Gregg Solomon, Jenny Ganger, James Thomas, John Houde, Claudia Uller, Edson Miyamoto, among others, have had a major impact on my thinking of all aspects of cognitive science. I am glad to have shared with you that wonderful sense of an intellectual community.

I am extremely grateful to the undergraduate research assistants without whom none of these projects would have been possible: Babak Azad-Tatari, Lya Ana Batlle, Hilary Bromberg, Stormy Charles, James Choung, Aphrodite

Kakouros, Jessica Penney, Creola Petrescu, Michael Schlaffer, Jeannie Tyan, Alissa Whitney, Kitty Wong, and especially the three undergraduates who have done their independent projects with me, Rosa Arriaga, Anastasia Ginzbursky, and Kyra Raphaelidis. Most of all, I would like to thank the research assistants who have kept the lab running smoothly and efficiently and who have put up with my moments of "insanity": Laura Klatt, Kim Collins, and especially Jenny Welch.

Thanks to Michelle Hollander and Marie Coppola for providing technical assistance for the projects on inflectional morphology, although they are not included in the thesis.

My profound gratitude to the babies and parents who participated in the experiments reported in this thesis. I hope this research has contributed something to our understanding of the mind such that the babies and parents did not waste their precious time.

Thanks to Jan Ellertsen for rescuing me over and over from funding crises and to Pat Claffey for her library assistance.

My whole-hearted thanks to Cristina Sorrentino for being a dear friend, an invaluable colleague and collaborator. I have learned much about philosophy, cognitive science, and life from her. Cristina, I will be back for your thesis defense! I have faith in you.

Thanks to Josh Tenenbaum for helping me through the final stages of the thesis writing, for insightful comments on Chapter 1 and the defense talk, and for suggesting the title of the thesis. Since we disagree on almost all major issues in cognitive science, conversations with him have been particularly interesting, fun, and challenging.

I am grateful to many friends outside of MIT for good times and for having helped me through various crises, often unknowingly: Ai Qunwei, Tracey

Burns, Chen Han, Chen Xin, Lisa Fitzgibbon, Erica Foster, Huang Yucong, Fay Li, Elliza McGrand, Paska Permana, Ed Stein, Dylan Wei-tien Tsai, Wei Wei, Zach Woods, Zhong Gang, and especially Wang "Kathy" Yongwen.

During the last five years, Gary Marcus has taught me much at both the professional and the personal level. His insights and sharp mind have shaped my views of every aspect of cognitive science; his love, support, encouragement, patience, and jokes have helped me through many hard times. And much, much more that I cannot put into words. Thanks for everything, Gary. I hope we will always be friends.

Thanks to my father Xu Han and my brother Jay for their love and support; thanks to my uncle Kang Hongkuei for treating Jay and me as intellectual equals when we were hardly able to make a coherent argument, and for the first lessons on how to relish a good discussion regardless of winning or losing.

The greatest debt of all I owe to my mother, Kang Hongjin, who always believed in me and who has always been there when I needed her. Because of her, I have never lacked a role model in my life. I hope to have fulfilled some of the dreams that she did not fulfill for herself. I dedicate this thesis to her.

Preface

This thesis is composed of three papers/chapters that are independent, although conceptually closely related, bodies of work. Since each was designed and written to stand on its own, there is, inevitably, some redundancy in the presentation. The first paper provides a general theoretical framework in which the empirical work is situated; the intended audience is both philosophers of mind and language, and cognitive scientists and psychologists who are interested in natural language semantics and cognitive development. The second and third papers report empirical findings from infants and adults to support the main theoretical claims made in the first paper. The second paper has been accepted for publication in *Cognitive Psychology*. All references are placed together at the end of the document.

Table of Contents

Chapter 1

From Lot's Wife to a Pillar of Salt: Evidence that *Physical Object* is a Sortal Concept *

Abstract

A number of philosophers of language have proposed that people do not have conceptual access to "bare particulars" but only individuals that belong to different sortals which provide principles of individuation and identity. Sortals are concepts that underlie natural language count nouns. Many advocates of this view have argued that "object" is not a genuine sortal concept. In this paper, I argue that the arguments against "object" being a sortal become unconvincing if we apply the narrow sense of "object", namely bounded, coherent physical objects that move as a whole (Spelke, 1990). Furthermore, theoretical arguments and experimental evidence from young infants and adults suggest that "object" functions as a genuine sortal concept in our conceptual system. Implications for core cognitive architecture are discussed.

---

* I would like to thank Susan Carey, Elizabeth Spelke, Robert Stalnaker, John Macnamara, Gary Marcus, Cristina Sorrentino, and Sandeep Prasada for discussions of the subject matter. I also thank Jenny Ganger, Carson Schultze, Cristina Sorrentino, Robert Stalnaker, Joshua Tenenbaum, and especially Susan Carey and Gary Marcus for their painstaking comments on earlier drafts of the paper. Portions of this paper were presented at the 1995 Annual meeting of the Society for Philosophy and Psychology.

Please address correspondence to Fei Xu, E10-106, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 or E-mail fei@psyche.mit.edu.

1. Introduction

1.1 What is a sortal?

Since Frege (1884) first observed that one cannot count without specifying what to count, various philosophers and psychologists of language have argued that certain concepts dubbed "sortals", e.g., *car, person, dog*,[1] provide principles of individuation and numerical identity; these concepts tell us what to count as one instance of something and whether something is the same one as what we have seen before (Geach, 1962; Gupta, 1980; Hirsch, 1982; Macnamara, 1987; Macnamara & Reyes, 1994; Wiggins, 1967, 1980). Sortals are lexicalized as count nouns in natural languages that make the count/mass distinction. For example, a request to "count the red in this room" cannot be complied to: Should a red shirt be counted as one or should the shirt, the two sleeves, and two pockets be counted separately such that we have five reds? In contrast, a request to "count the shirts in this room" will receive a definite answer: a red shirt (with its sleeves and pockets) should be counted as one shirt, not two. Hence the count noun "shirt" gives us the principles for what to count as one shirt whereas the adjective "red" does not provide principles of counting. In general, other predicates besides count nouns, e.g., verbs or adjectives, do not serve the logical function of providing principles of individuation. We cannot count "sleeping" or "blue" unless we mean, e.g., count the naps you took or the blue birds.

Sortals also provide principles of identity. When a dog dies, even though we can trace a spatiotemporally connected path during this process, we nevertheless decide that the dog has gone out of existence. We cannot ask the

[1] Throughout the paper I will adopt the convention that all sortals be italicized and all mention of words be in quotes.

question "is this the same X" without using a sortal to specify what X is. For example, a grown-up is no longer the same baby she was when she was an infant, but she is still the same person throughout development. Again, adjectives and other grammatical categories do not provide such principles of identity. For instance, whether something is "the same red" does not have a definite answer unless we mean "the same *shade* of red" or "the same red *sweater*" -- count nouns such as "shade" and "sweater" provide the principles of identity.

1.2 Some fundamentals of a logic of sortals

These considerations have led some philosophers of language to develop a logic of sortals (Geach, 1962; Gupta, 1980; Wiggins, 1967, 1980; Hirsch, 1982; Macnamara, 1987). The fundamental tenet of a logic of sortals is there are no bare particulars; we cannot enumerate or trace identity without the support of a sortal. "Bare particulars" are the alleged individuals that have no properties of their own whatsoever but still serve as entities on which to hang properties. A demonstration of a bare particular may be the following. Suppose someone is pointing at some part of the visual scene and uttering the word "that". We may be able to figure out that the person intends to pick out part of the visual scene with a table present, but we would not know whether the person is pointing to the table, a color patch of the table, the millions of molecules of the table, or the table plus the dish that is sitting on it. The demonstrative "that", which is an example of a bare particular, does not pick out an individual for which we can trace identity over time. In model-theoretic semantics, the logical form for "The person is tall" in predicate calculus is "$\exists x$ person (x) & tall (x)." In this formulation, x is a bare particular -- It has no properties of its own but it still supports properties such as "being a person" or "is tall." The logic of sortals denies that we have conceptual access to bare particulars.

Three other important tenets are relevant to the present discussion. First, a principled distinction should be made between count nouns and other grammatical categories; second, the principles of individuation and identity supported by sortals cannot be reduced to some basic notion of spatiotemporal continuity; third, within the class of sortals, a distinction should be made between substance and stage (or phase) sortals.

Consider first the distinction between count nouns and other grammatical categories. Count nouns denote kinds which provide principles and criteria for individuation and identity whereas other grammatical categories do not. Adjectives, verbs, and prepositions are predicates of the individuals sorted by count nouns; their interpretations crucially depend on which count nouns they are predicated of, e.g., "good" as in "a good person" means something rather different from "good" as in "a good thief."

Second, principles of individuation and identity provided by sortals may override our basic criteria of identity based on spatiotemporal continuity. To borrow an example from Hirsch (1982): A car consigned to a crusher follows a spatiotemporally continuous path in the crushing process, but nevertheless at some point, the car goes out of existence. This is because the sortal *car* provides the criterion as to what counts as a car.

The third claim, defended in Wiggins (1980), makes a distinction between substance and stage (or phase) sortals. In a nutshell, a count noun is a substance sortal if instances of the kind it denotes cease to exist when they cease to be members of the kind specified by the sortal, e.g. *person, dog, tree, car*. In other words, substance sortals satisfy the condition that once something is no longer X, it is also "no longer". For example, when a person dies, he ceases to be a member of the kind person and he goes out of existence. Hence "person" is a substance sortal. Substance sortals contrast with phase sortals such as baby or tadpole, which do not have this property -- a baby does not cease to exist when she grows up even though she or he is no longer a member of the kind baby. Similarly, a tadpole does not cease to exist when it becomes a frog although it is no longer a member of the kind tadpole. For Wiggins (1980), only substance sortals are kinds.

1.3 A logic of sortals as an alternative formalism for natural language semantics

A logic of sortals is offered as an alternative for formalizing natural langauges such as English. As mentioned above, standard model-theoretic semantics posits bare particulars, i.e., attribute-free individuals. For example, the translation for "the man is tall" is "there is an x such that x is a man and x is tall." The x in this translation is a bare particular that has no properties of its own; "man" and "is tall" are treated as the same kind of predicates despite their difference in grammatical category.

Recently, Reyes, Macnamara, and Reyes (1993) and Macnamara and Reyes (1994) have argued that model-theoretic semantics runs into serious problems by positing such bare particulars. First, consider the following syllogism: "Every person on the bus is a baby" and "every baby on the bus is big". Each individual on the bus now has three attributes according to the representations of predicate calculus: being big, being a baby, and being a person. These two premises would lead to the inference that "every person on the bus is big". This is clearly not a valid syllogism because although a baby is a person, a big baby is not a big person. The trouble is that "big" when applied to "baby" means something different from what it means when applied to "person." Second, the relation between "passenger" and "person" is one of class inclusion. "Passenger" is interpreted as the subset of things (i.e., bare particulars) that have the property of being a passenger; "person" is the subset of things that have the property of being a person. The set for "passenger" is a subset of the set for "person". Therefore, each passenger is identical to a person. However, in real life, if Jodie Foster flies on USAir from San Francisco to Los Angeles in March, then from Boston to Paris in May, the airline would count her as two passengers, although she is, of course, one and the same person throughout. The problem is that class or set-theoretic inclusion relation does not allow the possibility that more than one passenger can be identified with each person.

A better formalism for a natural language like English, Reyes et al. (1993) and Macnamara and Reyes (1994) argue, would take into account the fact that individuals have to be typed by sortals. Employing category theory, a branch of mathematics, Macnamara, Reyes, and their colleagues have developed a detailed theory of kinds/sortals. Their system of kinds is a system of underlying maps among kinds, instead of class inclusions. A kind *person /passenger* is construed as the set of all persons/passengers that ever were, are, or will be. A member of the kind *passenger* may be identified with a member of the kind *person* by applying a function u: *passenger* ---> *person*. Thus it is possible that passenger A and passenger B map onto the same person.

Macnamara, Reyes, and their colleagues argue that for example, the logical translation for "the man is tall" is better represented as "there is an (x: man) such that (x: man) is tall". In this formalism, there is no x that stands by itself without the support of a sortal such as "man". The grammatical distinction between "man" and "is tall" is also respected in that the interpretation of the predicate "tall" now depends on which sortal it modifies. This alternative formalism will also help solve the problem of valid syllogisms (see La Palme Reyes, Macnamara, & Reyes, 1994, in press).

1.4 *Object* and *thing*: Candidate bare particulars or general, universal sortals?

It is crucial for sortal theorists such as Wiggins and Macnamara that bare particulars do not exist. If one could show that people had conceptual access to bare particulars, we would not need a logic of sortals to represent the semantics of natural languages: All count nouns as well as other grammatical categories could then be construed as predicates of these bare particulars. However, as demonstrated earlier, demonstratives such as "that", a good candidate for a bare particular, do not pick out individuals for which we can trace identity over time.

The existence of bare particulars may be devastating for the sortal approach to semantics. But even a weaker version of a bare particular would, as sortal theorists believe, cause serious damage. The weaker version would be to find a general, universal sortal such that all other sortals, e.g., *dog* or *car*, would be dispensable because they could be construed as predicates of this general, universal sortal. Note this would be a weak equivalent of finding a bare particular -- other count nouns as well as other predicates such as verbs and adjectives would be construed as predicates of this general, universal sortal. If such a general sortal existed, we would not need to draw a sharp line between count nouns and other grammatical categories and predicate calculus could be only slightly modified in order to represent natural language semantics: We could replace the Xs with this general sortal.

One might ask why the sortal theorists insist on *dog, tree,* and *person* being the right level of specificity for sortalhood. Implicitly or explicitly, all sortal theorists agree that a sortal should provide a satisfactory answer to the question "what is it" (Wiggins, 1980). *Dog, tree,* and *person* certainly fulfill this requirement.

A first glance at a natural language such as English, however, seems to give us some candidates for either bare particulars or general, universal sortals. Count nouns such as "object," "thing," or "entity" give the appearance of being either individuals that have no properties of their own but still serve as individuals on which to hang properties or general sortals that other specific sortals (e.g., *dog, car*) may be predicates of.

Not surprisingly, sortal theorists have argued that "object," "thing," or "entity" is not a sortal concept. For example, Wiggins (1980) says "For a formal concept like *entity* or *substance* has no autonomous individuative force of its own, and must be variously supplemented, wherever it appears in contexts of identification, according to the kind of the individual in question (p. 63)." "*Material object* is now ruled out from sortal status, and so are other dummy substantives, ... (p. 64)."

Three types of arguments have been put forth against "object" or "thing" being a sortal. The first type is that natural language terms such as "object" or "thing" do not individuate (Wiggins, 1980; Macnamara, 1987; Macnamara, 1994; La Palme Reyes, Macnamara, Reyes, & Zolfaghari, 1994). Macnamara (1994) says it clearly: "We cannot conceptually grasp an individual in a universal kind supposedly denoted by the count noun "thing" or "object" (p. 20)." The reason is that "thing" or "object" does not tell us what to count as one instance. If you were to count the things in the room, you might count the chair as a chair, four legs, plus one top. Hence six things altogether! Similarly, Hirsch (1982) claims that at least the broadest sense of the word "object" is not a sortal: "There may possibly be a completely permissive sense of the word "object" which applies in fact to any aggregate of matter, however spatially discontinuous" (p. 97). This sense of "object", or even the sense of the "object" that applies to any continuous portion of matter, certainly does not give us countable individuals.

The second type of argument is that "object" or "thing" does not provide principles of numerical identity. The Old Testament (Genesis, chapter 19) tells the story of Lot's wife. Lot and his wife were told by the Lord "Escape for thy life; look not behind thee,... Then the Lord rained upon Sodom and upon Gomorrah brimstone and fire from the Lord out of heaven... But his wife looked back from behind him [Lot] and she became a pillar of salt." Wiggins (1980) claims that in this process, nothing persisted through time: Lot's wife ceased to exist and a pillar of salt came into being. According to Wiggins, there is no sortal concept, e.g., *object* or *thing*, that could answer the question of Lot's wife and the pillar of salt being the same what. He argues that short of inventing a sortal concept *woman-pillar*, "certainly there is no substantial sortal, ... suitable to cover the identity between Lot's wife and the forty foot pillar of salt that is still to be encountered even now on the Jebel Usdum near the Dead Sea (p. 61)." The difficulty with *object* or *thing* as candidate sortal concept in Lot's story, as I understand Wiggins, arises from the fact that in this story, an entity starts off with the persistence principle of one kind (i.e., *woman*) then exchanges that principle for the persistence principle of another kind (i.e., *pillar of salt*). In addition, Wiggins believes that the story of Lot's wife is incoherent since it violates actual laws of nature.

Finally, terms such as "object" or "thing" may be less good candidates for answering the question "what is it." If one were to ask the question "what is it", an answer such as "a cup" or "a person" would suffice. But if the answer were to be "a thing" or "an object", we still would not have any idea what that thing is! It is peculiar that "object" and "thing" are nevertheless lexicalized as count nouns even though they don't seem to behave in the same way as most other count nouns. One answer may be that these nouns are place-holders and not true sortals.

Although the English word "object" or "thing" may not be a sortal, as shown above, I will argue that for both adults and young infants, there is a sortal, *physical object*, which is more general than *person, car*, or *tree*. A physical object is defined as any three-dimensional, bounded entity that moves on a spatiotemporally continuous path (Spelke, 1990), which is a notion very close to Jackendoff's "maximally connected object" (Jackendoff, 1983). The English word "object" has multiple senses and this concept of physical object corresponds to one of the senses. In the rest of the paper, I will defend the claim that *physical object* (that is, one sense of the English word "object") is a sortal. Section 2 provides evidence that *physical object* is the first sortal for young infants; section 3 provides evidence that *physical object* is a sortal for adults and the aforementioned arguments against "object" being a sortal may be remedied; section 4 discusses the relation between *physical object* and other more specific sortals; and section 5 discusses advantages of building *physical object* as infants' first sortal concept and some possible learning mechanisms which will allow the infants to construct more specific sortals.

2. Evidence from infants: *physical object* as their first sortal

The philosophical literature on identity generally agrees that any explication of the concept of identity should satisfy Leibniz's Law, which says if x is identical to y, x and y should have exactly the same properties. Although Leibniz's Law is logically necessary for numerical identity, it does not give us a notion of how things persist through time and space. A psychologically real explication of the concept of identity, however, should include people's criteria for persistence over time, that is, how people decide whether something is the same one we have seen before.

Our criteria for individuation and identity may be roughly divided into two types: spatiotemporal information and property/kind information. The spatiotemporal criteria include the following generalizations: 1) one object cannot be at two places at the same time; 2) two objects cannot be at the same place at the same time; 3) objects travel on spatiotemporally connected paths. The property/kind criteria include the following generalizations: 1) upon seeing a member of a kind now (e.g., a cup) and a member of a different kind (e.g., a dog) at a later time, we infer there are two numerically distinct entities; 2) upon seeing a member of a kind now (e.g., a red block) and a member of the same kind with a different property (e.g. a blue block) at a later time, we (often) infer there are two numerically distinct entities. Note that the spatiotemporal criteria apply to all physical objects, regardless of kinds of object. The property/kind criteria, on the other hand, are kind-relative. Certain property changes signal a change in identity only within certain kinds of objects. For example, if you see a small chair now and a big chair later, you infer that there are two numerically distinct chairs. But if you see a small plant now and a larger one a few months later, it is not necessarily the case that there must be two distinct plants. One way to see what sortals adults or infants represent is by probing what criteria they use in individuation and identity judgments.

2.1 Evidence for *object* as a sortal in infancy

Psychological investigations have focused on what criteria are employed for individuating objects and deciding whether something is the same one as seen before. One psychologist who has done extensive work on infants' criteria of identity is T.G.Bower. In *Development in Infancy* (1974/1982), Bower presented some experimental evidence that infants use spatiotemporal rules to trace identity but before 5 months of age, infants do not use property differences to infer change of identity. In addition, he claimed that infants were guided by different spatiotemporal rules from adults. For infants, Bower claimed, stationary and moving objects are numerically distinct. Bower used a visual tracking paradigm in these studies. In one experiment, infants learned to track moving objects by turning their heads. In the test trials, the moving objects would suddenly stop. Bower found that infants kept turning their heads when the object stopped. He interpreted these results as showing that the infants thought that the moving object would continue to move along its path and the stationary object (which was moving until it stopped suddenly) was a different object. In the second experiment, Bower tested whether infants used property differences to establish object identity. A moving object, say a bunny, would disappear behind a screen, then another object, say a ball, would appear from behind the screen. Bower found that young infants kept tracking the new object and did not look back to the screen. He interpreted these results as showing that infants did not make the inference that the ball was a different object from the bunny. By 5 months of age, however, infants looked back at the screen. Bower interpreted this as indicating that infants realized that the ball and the bunny were two different objects and the bunny must have stayed behind the screen.

There are a number of serious methodological flaws in these experiments: the failure to stop head turning in the first experiment may be due to the fact that young infants do not have very good neck control at this age and hence cannot inhibit the head-turning motion when the object stops; the failure to look back at the screen in the second experiment could be due to a similar reason, or alternatively, it could be due to the fact that the infants were well aware that the ball was a different object from the bunny, but kept tracking because of its novelty. Furthermore, a number of researchers either failed to replicate Bower's findings or found that the looking back behavior was a function of the speed at which the objects were moving but not a function of the property differences, that is, the looking back behavior occurred equally often when the same object emerged from behind the screen as opposed to a different object (Muller & Aslin, 1978; Meicler & Gratch, 1980; Gratch, 1982). In sum, Bower's experiments do not give us any clear evidence about the infants' concept of object identity; however, his conjecture that infants use spatiotemporal information before using property information to trace identity turns out to be on the right track.

There is now considerable evidence in the infant cognition literature suggesting that infants as young as 4 or 5 months use all three spatiotemporal generalizations to trace identity, just like adults, but unlike adults, they do not use property/kind information until 10 to 12 months of age.

Spelke and Kestenbaum (1986) and Spelke, Kestenbaum, Simons, & Wein (1995) presented an ingenious experiment showing that 4-month-old infants understand that objects travel on spatiotemporally connected paths. In this experiment, two screens were lowered onto the stage, with some space in between them. The infant saw that a rod appeared from behind one screen, say the left one, moved to the left end of the stage, then returned behind the left screen. No object appeared between the two screens. After a short pause, a physically identical object appeared from behind the right screen, moved to the right end of the stage, then returned behind the right screen (see Figure 1 for a modified version of this experiment using different objects). This event was repeated until the infant reached the habituation criterion, which was defined as the average looking time of the last three habituation trials being half of the first three trials. The screens were then removed to reveal one of two outcomes: the expected outcome (from an adult's point of view) of two identical rods or the unexpected outcome of just a single rod. The infants looked longer at the one-rod outcome, suggesting that they, like adults, had expected two rods and were surprised to see just one. When the rod did appear in the space between the two screens, on the other hand, the infants looked about equally at the one-rod and two-rod outcomes, as if undecided as to how many rods were behind the screens. Xu & Carey (in press) replicated the above finding with 10-month-olds using a rather different set of objects, e.g., toy ducks, balls, elephants, and trucks. Wynn (1992), using a somewhat different paradigm, had a similar finding with 5-month-olds.

Baillargeon, Spelke, and Wasserman (1985) presented evidence that infants as young as 5 months understand that two objects cannot be at the same place at the same time. In these experiments a drawbridge-like rotating screen facing the infants was introduced. After the infant was habituated to the rotating screen going 180 degrees back lying flat on the stage floor, a box was introduced and placed behind the screen. The rotation resumed and sometimes the screen stopped short of 180 degrees (the expected event since the box was behind it) and sometimes the screen rotated all the way back to 180 degrees (the unexpected event; see Figure 2). Infants looked reliably longer at the unexpected event, suggesting that they expected the box to remain behind the screen and the screen and the box cannot occupy the same space at the same time. Baillargeon & DeVos (1991), using a somewhat different paradigm, found that infants as young as 3 and 1/2 months understand this generalization.

Baillargeon & Graber (1987) showed that 5-month-old infants understand that one object cannot be at two places at the same time. In one of the experiments, infants were habituated to a tall rabbit going behind a screen and appearing on the other side. Then the middle section of the top half of the screen was removed such that if the tall rabbit would appear in the middle. If the rabbit did not appear in the window, the infants were surprised. If the infants were shown two tall rabbits by the screen initially, they were not surprised to observe that no rabbit appeared in the window (see Figure 3). Infants can only succeed if they interpreted the two identical-looking rabbits as two distinct rabbits using the location information.

Finally, there is evidence that suggests that infants in these experiments quantified over objects as discrete entities and did not simply keep track of the amount of stuff. In several experiments with 8-month-old infants, Huntley-Fenner & Carey (1995) showed that infants failed to count piles of sand even when they were given clear location information to help them individuate sand piles. In other words, infants do not seem to track the amount of stuff present in an event, which suggests that in the experiments involving solid objects, they quantified over individuals.

Taken together, these results speak against the traditional view of the initial cognitive state of the young infant. Both Piaget (1954) and Quine (1960) believed that infants' world does not consist of persisting objects, which implies that the infant does not have any criteria for individuation or identity. The results discussed above, however, clearly show that young infants have some criteria for individuation and identity.

There are at least two interpretations of which sortals underlie the capacity revealed by the above experiments. One is that infants represent specific sortals such as *doll, rod, box, toy rabbit*, and others. After all, all sortals (which refer to physical entities in the world) are subject to the spatiotemporal constraints on individuation and identity. However, a more conservative interpretation is that the sortal concept underlying these successes is *physical object* since these criteria apply to all physical objects, the experiments I have described involved a variety of different objects, and none of the experiments required any representation of individuation and identity criteria for specific sortals. *Physical object* is a sortal since it provides criteria for individuation and tracing identity; these criteria are spatiotemporal in nature. Thus further evidence is needed to decide which interpretation of these results is correct.

2.2 Evidence for *object* as the <u>first</u> sortal in infancy

Do young infants also represent other more specific sortals such as *ball* or *bottle* or do they represent only the sortal *physical object*? Xu & Carey (in press) devised further experiments to address this question. For "ball" or "bottle" to be a sortal, minimally the infant should be able to use the property differences between a bottle and a ball to set up representations of two numerically distinct individuals. In this experiment, a single screen was lowered on the stage. Ten-month-old infants saw that a ball appeared from behind the screen, moved to the left end of the stage and stopped. The infant's looking time was monitored, then the ball returned behind the screen. After a short pause, a bottle appeared from behind the screen, moved to the right end of the stage and stopped. Again the infant looked at it until she turned away, then the bottle returned behind the screen. This event was repeated until the infant reached habituation criterion. When the screen was removed, the outcomes were either two objects, one ball and one bottle (expected outcome), or only one of the two objects (unexpected outcome; see Figure 4). The rationale was exactly the same as the earlier experiments: if the infant is able to use the kind/property difference between the ball and the bottle to infer two distinct objects, she should look longer at the one object outcome. Surprisingly, these 10-month-old infants failed to look longer at the unexpected (one-object) outcome. They simply exhibited a baseline preference for looking at two objects as if they had never seen the event. Success in this task may or may not show that the infants represent sortals such as *ball* or *bottle*, but the failure suggests that they do not represent sortals *ball* or *bottle*. To ensure that the result in this experiment was not an artifact of the method we employed, a control version was carried out. The infants were simply shown the two objects simultaneously at the beginning of the experiment, that is, they were given spatiotemporal evidence that there were two objects (see Figure 5). The experiment then unfolded as before and the outcomes were the same as before. The infants in this control group looked longer at the unexpected outcome of one object, suggesting that the method was sensitive and reliable.

One may wonder if the infants even coded the properties or features of the objects. If the infants were not capable of coding the properties, one would not expect them to be able to succeed at this task. To block this alternative interpretation, Xu & Carey devised an experiment contrasting seeing a ball followed by a bottle and seeing one ball over and over again. We found that it took longer for the infants to habituate to the sequence ball, bottle, ball, bottle than the sequence ball, ball, ball, ball, which suggests that the infants coded the properties of the objects. In other words, even though the infants were capable of encoding the properties of the objects, they did not use the property differences to infer that there were two distinct objects.

How did the 10-month-old infants represent the event in these experiments? It is likely that the infants represented the event as an object with some features, an object with some features, ... and they did not commit themselves to whether there were one or two objects behind the screen. The longer looking at the two-object outcome simply reflected their intrinsic preference for looking at two objects and not a positive expectation of one object. In other words, the spatiotemporal evidence is insufficient for the infant to set up a representation of two distinct objects.

Of course we have not exhausted all possible kind contrasts, but I believe that we have surveyed a fairly representative repertoire. Some of our stimuli (e.g., toy duck vs. ball, and toy truck vs. toy elephant) span categories of animate vs. artifact and vehicle vs. animate, and the other stimuli were highly familiar to 10-month-old infants. Current studies are underway to investigate changes that cut across certain ontological boundaries, e.g., a live gerbil vs. a chair, or a person vs. a large box.

Further experiments in Xu & Carey (in press) showed that twelve-month-old infants succeed at this task. This is at least suggestive that the older infants may have sortal concepts *ball* and *bottle*, since it seems likely that they represented the event as a bottle emerging from behind the screen followed by a ball. Since the two exemplars belong to two different sortals/kinds, they must be two distinct objects. However, an alternative representation not involving sortals *bottle* and *ball* could underlie this success. Infants may have learned that a round thing with pink and green stripes does not change into a cylindrical thing with a rubber top, that is, they may be using the property differences between a ball and a bottle to infer change of identity. Nonetheless, the following finding from this series of studies suggests that this task may be directly relevant to the infants' representation of sortals. In two versions of the experiment where 10-month-olds failed as a group (using the same paradigm as above), we found a correlation between word comprehension score and performance on the task. Within 10-month-olds, the infants who were judged by their parents to understand at least 2 of the 4 nouns that name the objects in the task (i.e., ball, bottle, book, and cup) succeeded at the task whereas the infants who understood only one or none of these nouns failed. This rather tight relation between word comprehension and performance suggests that the infants who succeeded may have indeed used the kind difference as opposed to just property differences to make the inference. Their representation of the event may have been that a ball appeared then disappeared, followed by a bottle, then a ball again, a bottle again, etc. If the two objects belong to different kinds, they must be two distinct objects. However, this representation was only possible for infants who already knew the nouns. For the infants who did not know the nouns, detection of the properties such as color, shape, and texture did not help them infer that there were two objects behind the screen.[2]

[2] It is possible that the two processes, noun comprehension and success at the individuation task, are merely correlated (i.e., the "smart kids are just smart" confound). I cannot rule out this possibility at the moment. Future experiments will address this issue.

The experimental evidence reviewed above suggests that *physical object* is the first sortal concept infants represent and it is not until 10 to 12 months of age that infants represent more specific sortals such as *ball* or *bottle*. Preliminary results from two series of additional experiments provide converging evidence for this claim (Xu & Welch, 1995; Xu, Carey, Raphaelidis, & Ginzbursky, 1995). The sortal *physical object* not only provides criteria for individuation and identity, but also carries with it a number of principles that guide adults' and infants' reasoning. Spelke (1990) and Spelke, Breinlinger, Macomber, & Jacobson (1992) proposed three principles that guide infants' reasoning about objects and argued that these principles are at the core of adults' knowledge of objects: cohesion (objects are connected and bounded bodies that maintain both their connectedness and their boundaries as they move), continuity (objects exist and move continuously, such that each object traces exactly one connected path over space and time), and contact (objects act upon each other if and only if they touch). There is also evidence from studies of young infants' reaching behavior that these principles apply to real three-dimensional objects and not just merely figures as in figure and ground (Hofsten & Spelke, 1985; Spelke, Hofsten, & Kestenbaum, 1989).

2.4. Distinguishing a category and a sortal

It is worth pausing for one moment to compare the findings of Xu & Carey (in press) with those of earlier infant habituation studies. Several studies have shown that infants as young as 3 or 4 months can form categories such as table, dog, or tiger (e.g., Cohen & Younger, 1983; Quinn & Eimas, 1993; Eimas & Quinn, 1994). In these experiments, infants were habituated to exemplars of a given category, say dog, then they were shown a new exemplar from the same category, say another dog, or an exemplar from a different category, say a cup.

Infants dishabituated to the exemplar from the new category but remained uninterested to the exemplar from the familiar category. Furthermore, the infants were able to discriminate among the exemplars from the familiar category. These findings have been used to argue that infants have the representations of kinds that are necessary for learning natural language count nouns (Macnamara, 1987; Mandler, Bauer, & McDonough, 1991; Roberts & Horowitz, 1986).

There are three possible underlying representations given the habituation studies. First, the infants could be applying some similarity metric which distinguishes dog-ness from cup-ness, with no commitment to these exemplars being persisting objects. Second, given the work of Spelke, Baillargeon, and their colleagues which showed that young infants do represent persisting objects, the infants' representation of the events was more likely to be of the sort "an object with dog-properties, an object with somewhat different dog-properties, ... an object with cup-properties," with no commitment as to whether the dog and the cup were two distinct objects. Third, the infants might have represented these events as "a dog, another dog, ... a cup which is a distinct object from the dog." Yet the experimental paradigm used in these habituation studies does not tease apart which of these representations was underlying the habituation-dishabituation looking time pattern. Xu & Carey (1995)'s findings suggest that the second possibility, i.e., the young infants' representation was "an object with dog-properties," was correct.

3. Arguments for *physical object* as a sortal in the adult's conceptual system

Although I have presented empirical evidence that *physical object* may be the first sortal concept for infants, it is still possible that *physical object* is not a sortal in the adult's conceptual system. That is, in the course of development, infants come to construct more specific sortals such as *bottle* , *ball*, and *dog*, then abandon *physical object* completely. Below I will present some empirical as well as theoretical arguments that *physical object* functions as a genuine sortal even for adults.

Since I have claimed that *physical object* is one sense of the English word "object", I will first show that if we apply this narrower sense, the aforementioned arguments against "object" being a sortal become unconvincing .

3.1 Does *object* provide principles and criteria for individuation?

First consider the question of criteria for individuation. Imagine that you are asked to count the objects in a room that contains tables, chairs, mirrors, books, and other household items. Intuitively, each chair or each table counts as one object and nobody will count a table as five objects because the table has a top and four legs! To test this empirically, my colleagues and I have recently carried out an experiment where adults were asked how many object there were in a display which consisted of a toy duck perching on top of a toy car (Xu & Welch, 1995). All subjects reported that they saw two objects; none counted the eyes, the head, the wings of the duck or the wheels, the doors and windows of the car, contrary to Macnamara (1994). The consequence of perceiving the display as two objects was that subjects predicted that they would move independently of each other. Of course when asked to carry out the same task in a normal room with hundreds of items we may find that subjects vary somewhat on what exactly counts as an object, but I suspect that pages of a book and the letters written on a blackboard would not be counted as objects. In other words, "eye," "tooth," and "page" are perfectly good sortals, yet when one is asked to count "objects," separate movability becomes a very important criterion. What makes people count tables, chairs, and people but not legs of tables, tops of chairs, and eyes if "object" is not a sortal that provides criteria for individuation? When asked to count "objects," people readily apply the word "object" in accord with the definition of a physical object that I provided above: To constitute a countable object, an aggregate of matter has to be coherent and retains its boundaries as it moves in space and time. The sortal *physical object* (which is one sense of the English word "object") provides principles of individuation, just like any other sortal.

Now consider the second argument, brought forth by Hirsch (1982). My intuition is that there is no sense of the word "object" that is defined by "any aggregate of matter". For example, even if one is instructed to count the objects in a room using the broadest sense of "object", nobody will count the table plus the wall, or the table plus the chair, as one single object, although according to Hirsch "any aggregate of matter" should suffice being an object. But even Hirsch's narrower definition of object -- spatially continuous aggregates of matter -- is not used in everyday life. Imagine that I put a chair on top of a table such that there is direct contact between the two -- now together they constitute a spatially continuous aggregate of matter. We would still not count the table plus the chair as one object. Or suppose that I poured a jar of sand on the cover of a book, nobody would count that the book plus the pile of sand as one object. In general, being spatially continuous is far from being a sufficient condition for object-hood in our conceptual system.

3.2 Does *object* provide criteria for numerical identity?

Next consider the story of Lot's wife, which seems to pose a special challenge for all sortal theorists. Indeed, given our knowledge about the physical world, the story violates the laws of nature. However, since we do not have any trouble conceptualizing the event and understanding the story, it would be hard to argue that the story is simply "incoherent". If it were incoherent, it seems that our conceptual system should simply break down, as in the case of "a round square." Moreover, a piece of linguistic evidence may force us to come up with a sortal that covers both Lot's wife and the pillar of salt. Suppose that we find a pillar of salt standing in the wild and our informant points to it and says, "That used to be Lot's beloved wife." The demonstrative "that" is uninterpretable without a sortal because you could mean the collection of molecules, pillar of salt, collection of molecules at that very moment, and so forth. Which sortal underlies "that" depends on how we understand the utterance. What is being said, in effect, is that "<u>That</u> used to be Lot's wife; <u>that</u> is now a pillar of salt." This usage presupposes that <u>something</u> persisted through the two phases of whatever "that" is, a phase of being Lot's wife and a second phase of being a pillar of salt. In other words, the sortal underlying the use of "that" has to be a sortal that covers both the stages of Lot's wife and the stages of the pillar of salt. For those of us who believe in souls, the spiritual essence may have survived this dramatic metamorphosis. For those of us who do not believe in spirits, and if we assume the mechanism by which the change took place was that somehow every bit of Lot's wife has been transformed into a bit of sodium chloride, I suggest that *physical object* is the sortal that supports the demonstrative "that". Therefore the equivalent of the above utterance is the following: "The physical object over there was Lot's wife, a person, and it is now a pillar of salt."

3.3 "What is it"

The final argument against "object" being a sortal is that it does not answer the question "what is it." It is true that once we know the names *table, computer, tree,* or *dog,* a question such as "what is it" demands such a specific sortal. However, when we encounter novel objects that we have never seen before, the answer "it is an object" is acceptable. This answer is not as vacuous as it initially appears, because we would only apply this label "an object" if we believe that this novel individual is three-dimensional, bounded and coherent. A puddle of some unknown liquid will not be called "an object"!

Spelke (personal communication) pointed out to me that it may simply be pragmatically odd to answer "an object" when asked "what is it." The "it" has already picked out some object in the array and the question "what is it" asks for further information.

I hope to have shown that the arguments against "object" being a sortal can be countered by applying the narrow sense of the word "object", defined as *physical object*. In the next section, I will present some additional examples (some of them generalized from the above cases) to further strengthen the position that *physical object* is a sortal.

3.4. Some additional examples

Most objects that we encounter in daily life, e.g., cars, trees, rocks, dogs, and pieces of clothing, are relatively familiar. Encounters with these objects immediately invoke our vast knowledge about them: Cars are for transportation and they are generally made of metal and plastic; clothes keep us warm and they are made of cotton and other fabrics. Our conceptual system assigns objects into object kinds; the inferences we make are based on what kind of object we are dealing with. We individuate and trace the identity of objects by taking into account what kind of object they are.

Now imagine encountering something that we have never seen before, something that cannot be assimilated into one of the kinds we know about, can we still trace its identity over time? Consider Hirsch's (1982) example of a child who grows up on a farm and who has never seen a car before. Upon seeing a car moving in open field, can the child make any judgement about the identity of the car over time? As Hirsch argues, the following would never happen: after a while the child says, "the object I was looking at was first rather wide and very oddly shaped, but now it is much more square." Meanwhile he gestures with his hands to show that he was in fact piecing together the whole car and then just the middle section of the car without its front hood and back trunk even though the car has not undergone any qualitative or quantitative changes.

What prevents the child, or any adult, from making such a judgment? Hirsch (1982) argues for the existence of a basic rule stating that "trace an object's career by following a spatiotemporally and qualitatively continuous path which minimizes changes as far as possible." However it is difficult to make precise the notion of minimizing changes because one can minimize change along different dimensions, e.g., minimizing change of size may not be minimizing change of color. I suggest that it is the concept of a *physical object* that guides our judgment in this case, because the concept of *physical object* holds the object together as long as no piece of it falls off and starts to move independently.

A second example comes from "gobots" or "transformers" -- Something one can get from a toy store which can take the form of a robot as well as, say a space ship. A gobot is neither a robot nor a space ship. However, adults judge that it is the same object when the robot is transformed into a space ship.

Another source of evidence that *physical object* is a sortal comes from metamorphoses in fairy tales. Adults appear to have little trouble tracing the identity of a fictional character who at one moment is the prince and the next moment turns into a frog. One possible explanation is that this is how our perceptual system is built; we cannot help but perceive the spatiotemporally continuous changes of a prince turning into a frog. However, this cannot be the whole story. That is, it is not the case that the prince and the frog *appear* to be one and the same character; instead I would argue that at the conceptual level there is *one and only one* character. We would not try to look for the prince when the frog is present and we would not make inferences about two distinct characters but only one: the prince-frog character. It would be dangerous to postulate a sortal *prince-frog*, since that would lead to allowing an infinite number of sortals and render the theory with no explanatory power. A possible solution, proposed by La Palme Reyes (1994), is that the prince and the frog are the same *living being*, which persists through the dramatic appearance changes. She generalizes this case to all cases of metamorphosis, arguing that we sometimes invoke rather abstract sortals such as *soul* as our covering concept (which is the concept that specifies what persists through the changes). The key here is that a sortal concept is needed in order to understand these transformation that seem to express identity across kinds. In some of the cases, we need to invoke the sortal*physical object*. In the movie *Cinderella*, for example, a pumpkin is turned into a chariot. In this case, *animal* or *soul* would not be the appropriate sortal concept, yet *physical object* will do the job. Different parts of the pumpkin have been turned into parts of the chariot by some imaginary and magical mechanism, but as a whole it is still the same physical object. It is not just a case of the pumpkin ceasing to exist and the chariot comes to being, for something has to have persisted through time to allow us to utter the sentence "it used to be a pumpkin" while pointing at the chariot. Note this line of argument can be applied to the story of Lot's wife as well since it is a case of metamorphoses[3].

Finally consider the example of the car-crusher. The sortal "car" allows us to override spatiotemporal continuity; we decide that at some point the car goes out of existence and has been replaced by a pile of metal and plastic. However, certain strange situation arises in this process of crushing. Many would say that the car ceased to exist and a pile of metal and plastic came into being. But again, just as in the case of Lot's wife, we can point to the pile of metal and plastic and say, "that used to be a car," and we have no trouble understanding such an utterance. The sentence presupposes that something has persist in this crushing process, a *physical object*. Although no one would deny that "car" is a substance sortal and not just physical object plus some accidental properties, under these circumstances we behave as if we temporally suspend the status of car as a substance sortal, and think of it as a phase/stage sortal such that the life of the object has been divided into a car phase and a pile of metal and plastic phase.

These examples may resemble a well-known perceptual phenomenon, apparent motion. The classic apparent motion phenomenon is demonstrated by the following paradigm: if two points of light flashing alternately are set at a certain distance from each other and the interval of flashes is set at a certain

---

[3] Elizabeth Spelke pointed out to me that in virtually all metaphoses, the transformations were told in such a way that they did not violate spatiotemporal continuity, e.g., it is incomprehensible to us that the frog could vanish on Tuesday then the prince would appear somewhere else on Thursday. It seems a conceptual necessity that continuity be preserved in order for us to understand these fictional cases. Wiggins and others have no explanation about this.

value, we perceive one point of light traveling back and forth between the two locations. The subject may well know that there are really two points of light, but she cannot help it but see one point of light going back and forth. Presumably this is because our perceptual system manages to 'fool' us in this particular situation; the perceptual system is built such that this kind of illusions can occur and it appears that our conceptual understanding has no control over it. One might say that all of the examples I brought up above are of similar flavor as apparent motion. But there is a crucial difference: in all of the apparent motion cases, the display looks like something but our conceptual system is aware that something else is really going on. The inferences we make in those circumstances will be based on our belief that there are two points of light and not on the appearance that there is only one point of light. For the examples above, however, we could think of the prince and frog as two individuals, for our conceptual system has no mechanism that would allow such transformation. But we don't. We think of the prince-frog character as one individual, Lot's wife and the pillar of salt as one object, and the car and the pile of metal and plastic as one thing! Our inferences will be based on these accommodations that our conceptual system has come up with to deal with the situation.

To sum up, several cases demonstrate that adults utilize the sortal *physical object* in their construals of the world. Although we are not often forced to conceptualize the world in terms of physical objects instead of cars, trees, and tables, we resort to the sortal *physical object* under many somewhat out of the ordinary circumstances.

4. The relation between *physical object* and other more specific sortals

La Palme Reyes, Macnamara, Reyes, & Zolfaghari (1994) proposed that the relations among kinds are best characterized by underlying maps. My proposal for the relation between *physical object* and more specific sortals will be essentially an extension of their theory.

La Palme Reyes et al. (1994) proposed that the relation between a phase sortal such as *passenger* and a substance sortal such as *person* is one of underlying map as opposed to class inclusion. An underlying map is simply a function that maps members of a set A to members of a set B. Note unlike class inclusion relations, it is possible to map more than one member of A onto a single member of B. For example, a passenger from set A is mapped onto a person from set B -- u: *passenger* --> *person*. In this process, a member of the kind *passenger*, p, is identified with u(p), a member of the kind *person*, a. Thus u(p) is the person underlying the passenger p. It is also possible to have more than one passenger be mapped onto one person. For example, a passenger, p, is identified with a person, u(p); another passenger, p', is identified with person, u(p'). If u(p) = u(p'), the two passengers would map onto one and the same person.

Macnamara and his colleagues argue that the relation between *cow* and *animal* is also one of underlying map even though *cow* is not a phase/stage sortal. The mechanism is the same in the two cases (see Macnamara, Reyes, & La Palme Reyes, in press, for a detailed discussion). This proposal may be extended to the relation between a kind such as *car* and the kind *physical object*. There is an underlying map between members of the kind *car* and members of the kind *physical object*. A member of the kind *car* is identified with u(c), a member of the kind *physical object*.

Two issues should be clarified at this point. First, a car is <u>not</u> identical to a physical object. This is important because if a car were identical to a physical object, we would run into the following problem: Suppose we consign the car to a crusher, at certain point the car goes out of existence. But as I argued in the last section, the physical object has survived the crushing process. If the car were identical to the physical object, it would be absurd to say that the car has gone out of existence but the physical object has not. [4] Second, *physical object* is not a universal kind that all other kinds are predicates of since the relation between *physical objects* and other more specific sortals is not one of class inclusion. More importantly, *physical object* is certainly not a bare particular in the sense of an attribute-free support for attributes since physical object has its own criteria of individuation and identity. It is, after all, a sortal.

5. Implications for cognitive development

Intuitively adults conceptualize the world in terms of cars, people, trees, and telephones and they do not see them as types of physical objects. However, in a number of situations (discussed above), adults resort to the sortal *physical object* and temporarily suspend their beliefs that *car* and *tree* are substance sortals. Young infants, on the other hand, may begin with an innate mechanism to give them individuated entities, i.e., physical objects, and acquire more specific kinds/sortals later. This way of building a baby has three advantages.

First, it gives the baby an initial conceptual state that can develop into an adult-like system because the initial state has some criteria for individuation and identity. The traditional view holds that infants' world does not contain any objects persisting through time and space, hence there is no criteria for

---

4 I am indebted to Robert Stalnaker for this point.

individuation and identity (Piaget, 1954; Quine, 1960). An important question to ask is what kinds of learning mechanisms will enable the child to later develop a conceptual system that is based on adult's ontology of individuated entities. As far as I know, there are two proposals in the literature.

The first, suggested by Quine, is that by acquiring certain quantificational properties of a natural language that the infant comes to reconstruct her ontology. However, Soja, Carey, & Spelke (1991) have shown that the child has fully distinguished individuated and non-individuated entities long before they acquired the quantificational properties reflected in the syntax of English. In particular, well before children have mastered the count/mass distinction (as determined by their use of determiners), they distinguish individuated and non-individuated entities at the conceptual level. In fact, it is the conceptual distinction between individuated and non-individuated entities that guides the child's inferences in acquiring the meanings of nouns.

A second proposal, entertained but rejected by Kohler (1947) and Hirsch (1982), goes roughly as follows. Suppose a child starts off with a conceptualization of the world that does not have any principles of individuation and identity but only a quality space of some sort, the child can then observe that sets of sensations which have the same texture and color but differing in these respects from their environment tend to move together, i.e., behaving like units. The child then comes to learn that there are individuated units in the world. However, this is a non-starter. If the child experiences the world in terms of fleeting pieces from moment to moment, what would ever enable the child to notice that certain sensations move together? In order to observe that certain sensations tend to behave as units and notice the fact these sensations tend to appear and disappear together, one has to already have some criteria for individuation in order to pick out a set of sensations -- A good candidate seems to be the spatiotemporal criteria. But how could one ever learn those criteria for individuation? The answer seems to be "hard wired." Such accounts of learning simply cannot be formulated without presupposing some criteria for individuation. In other words, it would be an impossible task for a child who starts with a conceptual system void of criteria of individuation and identity to ever acquire the adult conceptual system.

The second advantage of building a baby this way is an argument from learnability. From the learner's point of view, the spatiotemporal criteria that I discussed in this paper are the most reliable whereas the property/kind criteria are less so. The spatiotemporal criteria apply across the board to all physical objects whereas the property/kind criteria vary from kind to kind. Presumably these kind-relative criteria have to be learned through interacting with the world[5]. Therefore the baby may be better off to start with the spatiotemporal criteria -- Having initially individuated the objects, they are in a good position to gradually learn about which of their properties stay stable over time.

A third advantage, related to the second, is a learnability argument suggested by Kellman (1993). He argues that because infants have certain limitations in attention span and motor control, it is difficult for an infant to correct a mistake in perception. So it is desirable that the initial perceptual capabilities of the child be the ones that have the highest ecological validity and that are the least misleading. Spatiotemporal information is, in general, a more valid indicator of the environment than information from static arrays. It is

[5] One could imagine a maturational process that would enable the child to represent more specific sortals. For instance, it is possible that the 10-month-old infants failed the task because they are yet to develop certain visual pathways that integrate information about object location and object features.

possible that the evolution of human perceptual system may have exploited such a relationship between spatiotemporal information and the environment. And an infant who initially depends heavily on spatiotemporal information in perceiving the world may be getting the most accurate picture of the environment and therefore survive more readily.

Finally, a few words on how a child might acquire the more specific sortals such as *car* or *dog*. There are at least two possibilities. First, infants may be built to expect that there are more specific substance sortals. Furthermore, infants may have an innate mapping between count nouns and sortals. Thus count nouns of a language may provide pointers for the child as to what sortals there are. The process of learning a count noun may also be the process of identifying a more specific sortal. Hall (1993) presented evidence that 2-year-olds expect novel count nouns to name substance sortals but not phase sortals, so it is possible that the child's initial bias is that count nouns map onto substance sortals or kinds.

Another possible way of acquiring sortals such as *car* or *dog* exploits the relationship of two possibly innate modules: an object module and a person module (Leslis, 1994). There is abundant evidence in the developmental psychology literature suggesting that infants react to people differently from other inanimate objects (Johnson & Morton, 1991; Legerstee, 1987, 1991; Woodward, Phillips, & Spelke, 1993). Some researchers have even argued for a "theory of mind" module whereby children are genetically endowed with certain principles specific for the purpose of understanding people (Leslie, 1994). Although there has not been any direct evidence suggesting that person is a sortal in the sense of providing principles of individuation and identity, let's speculate wildly for a moment. By itself, having two substance sortals, *physical* *object* and *person*, does not help. What we need is a substance sortal that is at some level conceptualized as a kind of physical object, therefore opening up the possibility of having other more specific substance sortals which initially fell under the sortal *physical object*. Here is how the sortal *person* might help. Suppose *person* is one of the very first substance sortals; meanwhile person may also obey at least some of the physical laws that objects obey, e.g., people move as a whole, people travel on spatiotemporally connected paths, and people do not go through solid barriers. That is, *person* is a substance sortal and at the same time it is subsumed under *physical object* in that person is a kind of physical object that obeys most of the laws that guide the behavior of physical objects. This realization may lead to the possibility that other physical objects, e.g., cars, telephones, dogs, may be substance sortals as well. Perhaps discovering criteria of individuation and identity other than the spatiotemporal ones could be sufficient evidence to lead the child to construct more specific sortals.

It may also be possible that the object and person modules employ completely different mechanisms for individuation and identity tracing. The object module, as Spelke and her colleagues have argued, uses spatiotemporal information only. The person module, in contrast, might use exclusively the property/kind information. After all, people are quintessentially unique individuals as demonstrated by the fact that every culture has proper names for people (though cultures vary on what else they give proper names to). If we assume a completely modular core cognitive architecture, in the sense of modules being informationally-encapsulated (Fodor, 1983), it is possible that some de-modularizing process will make available the property/kind information to the object module and this process will help the child construct more specific sortals.

6. Conclusions

I hope to have convinced the reader that for both adults and young infants, *physical object* functions as a sortal which provides criteria for individuation and identity. Although the child's conception of the world changes once she acquires more specific sortals such as *dog* or *car,* the sortal *physical object* provides the foundation of a conceptual system that has the logical resources necessary for our mature conceptualization of the world.

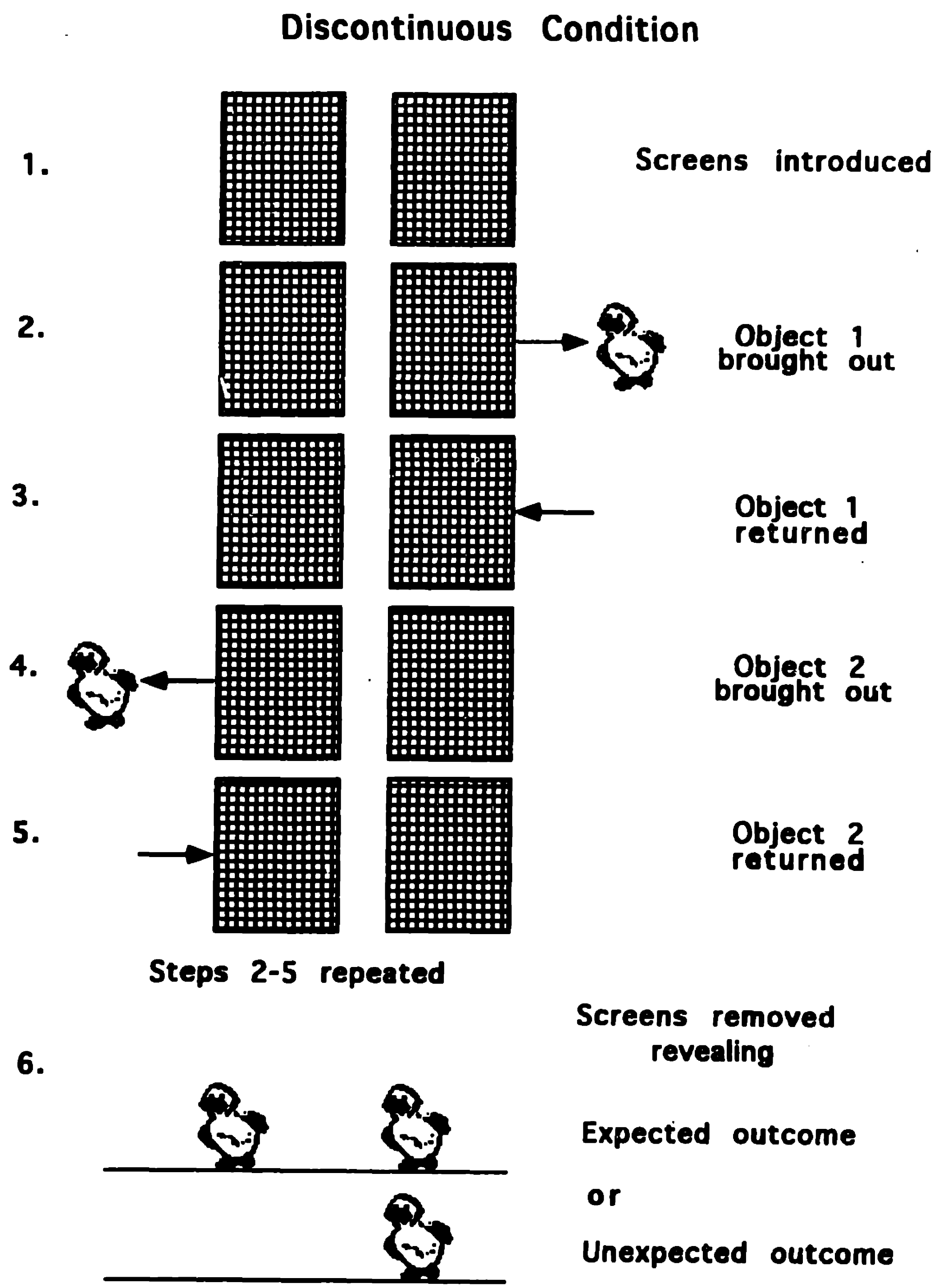

Discontinuous Condition
1.
Screens introduced
2.
Object 1 brought out
3.
Object 1 returned
4.
Object 2 brought out
5.
Object 2 returned
Steps 2-5 repeated
6.
Screens removed revealing
Expected outcome
or
Unexpected outcome

Figure 1

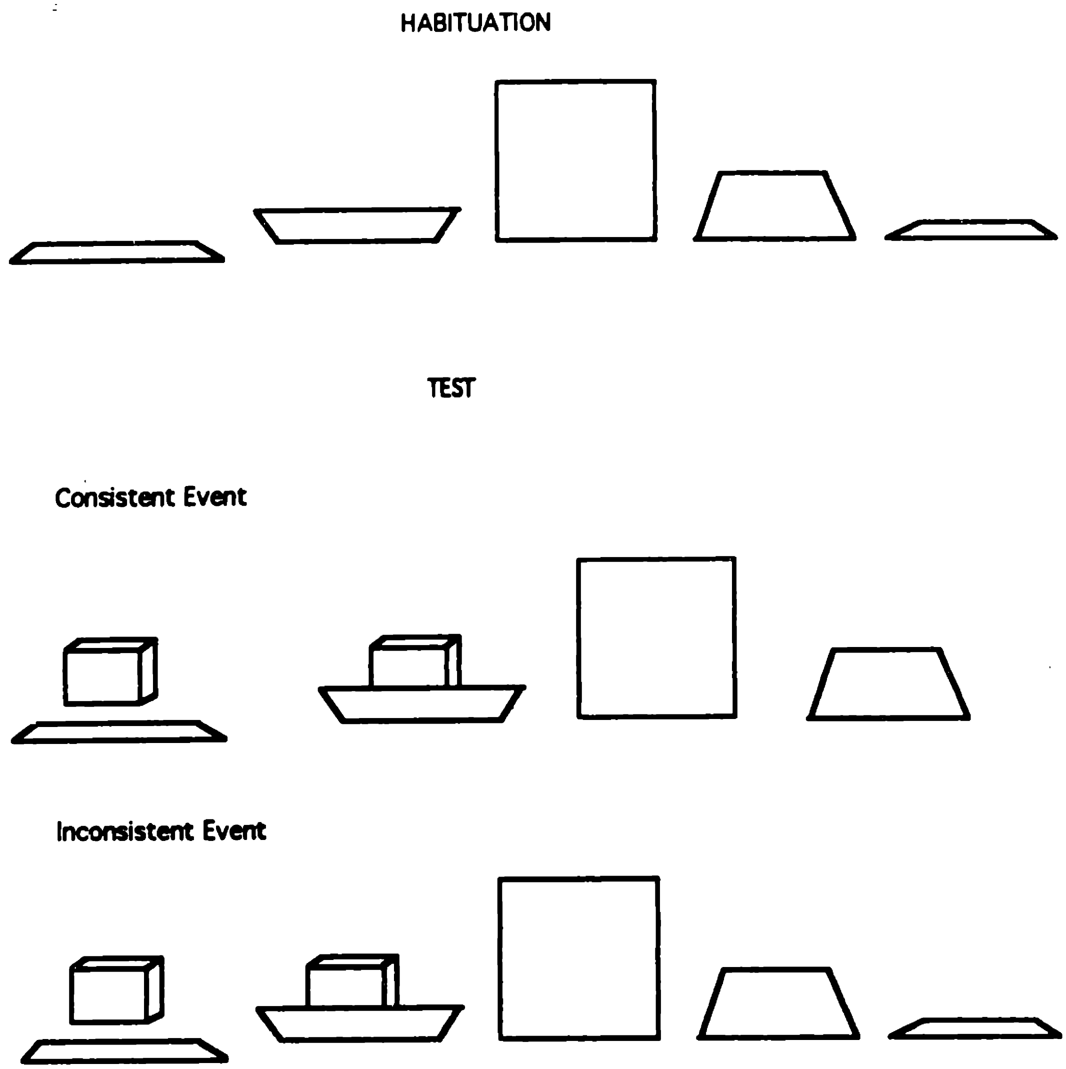


Figure 2

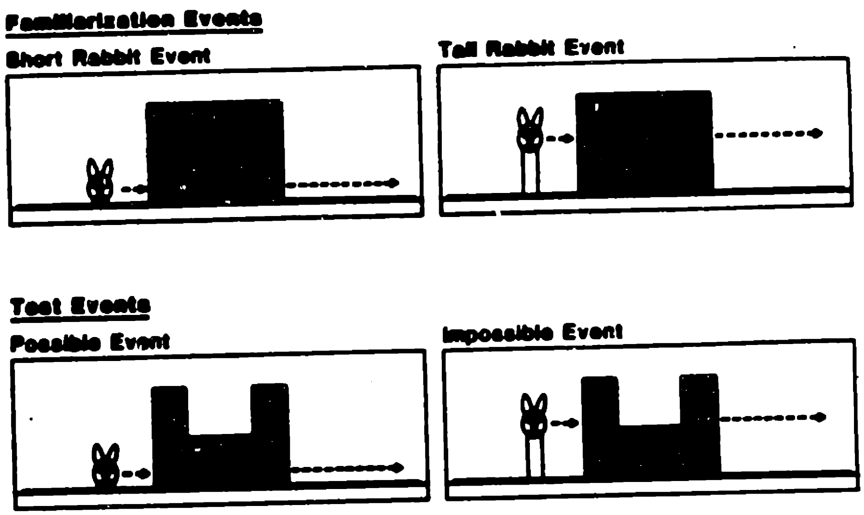

Familiarization Events
Short Rabbit Event
Tall Rabbit Event
Test Events
Possible Event
Impossible Event

Figure 3

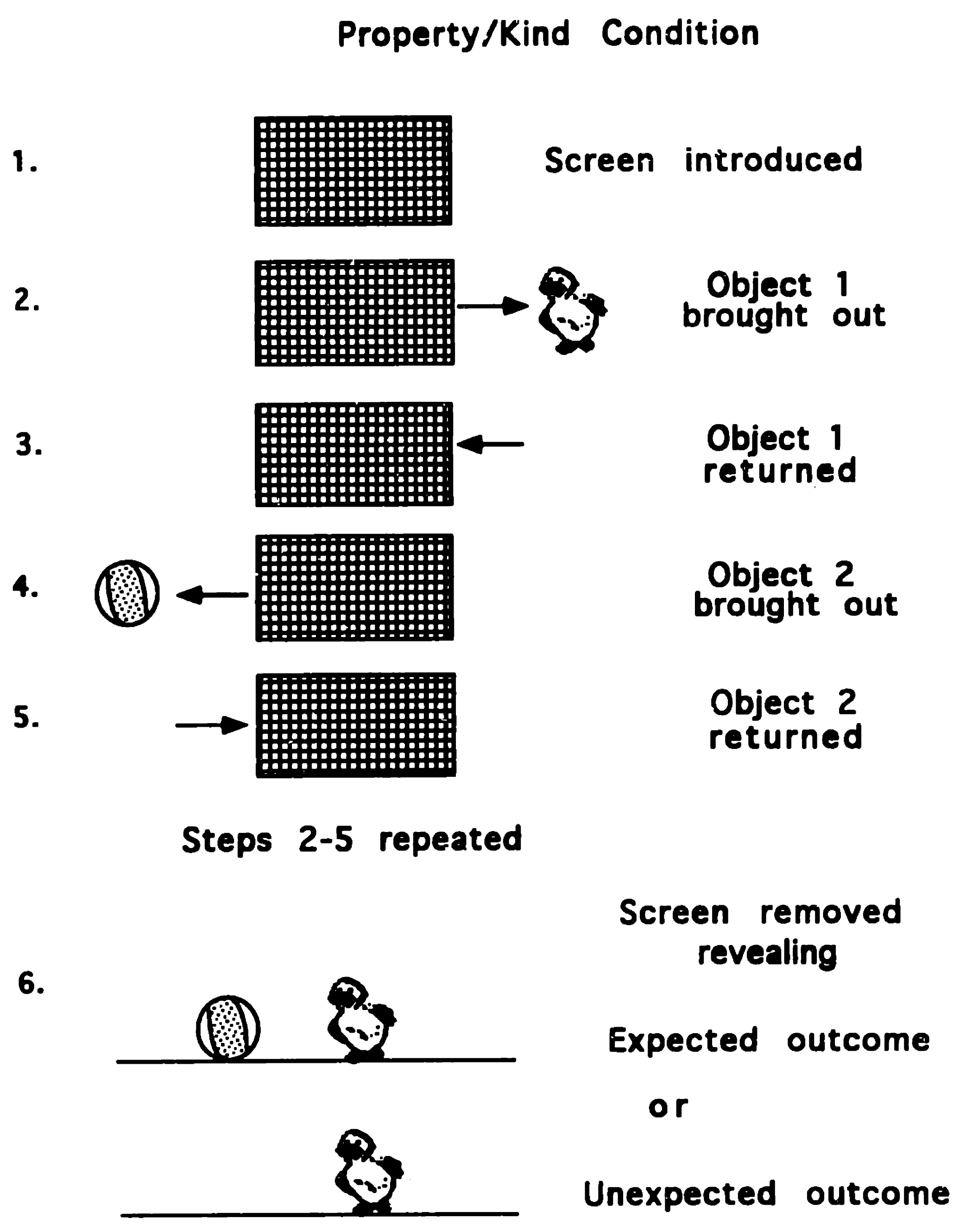

Property/Kind Condition
1.
Screen introduced
2.
Object 1 brought out
3.
Object 1 returned
4.
Object 2 brought out
5.
Object 2 returned
Steps 2-5 repeated
6.
Screen removed revealing
Expected outcome
or
Unexpected outcome

Figure 4

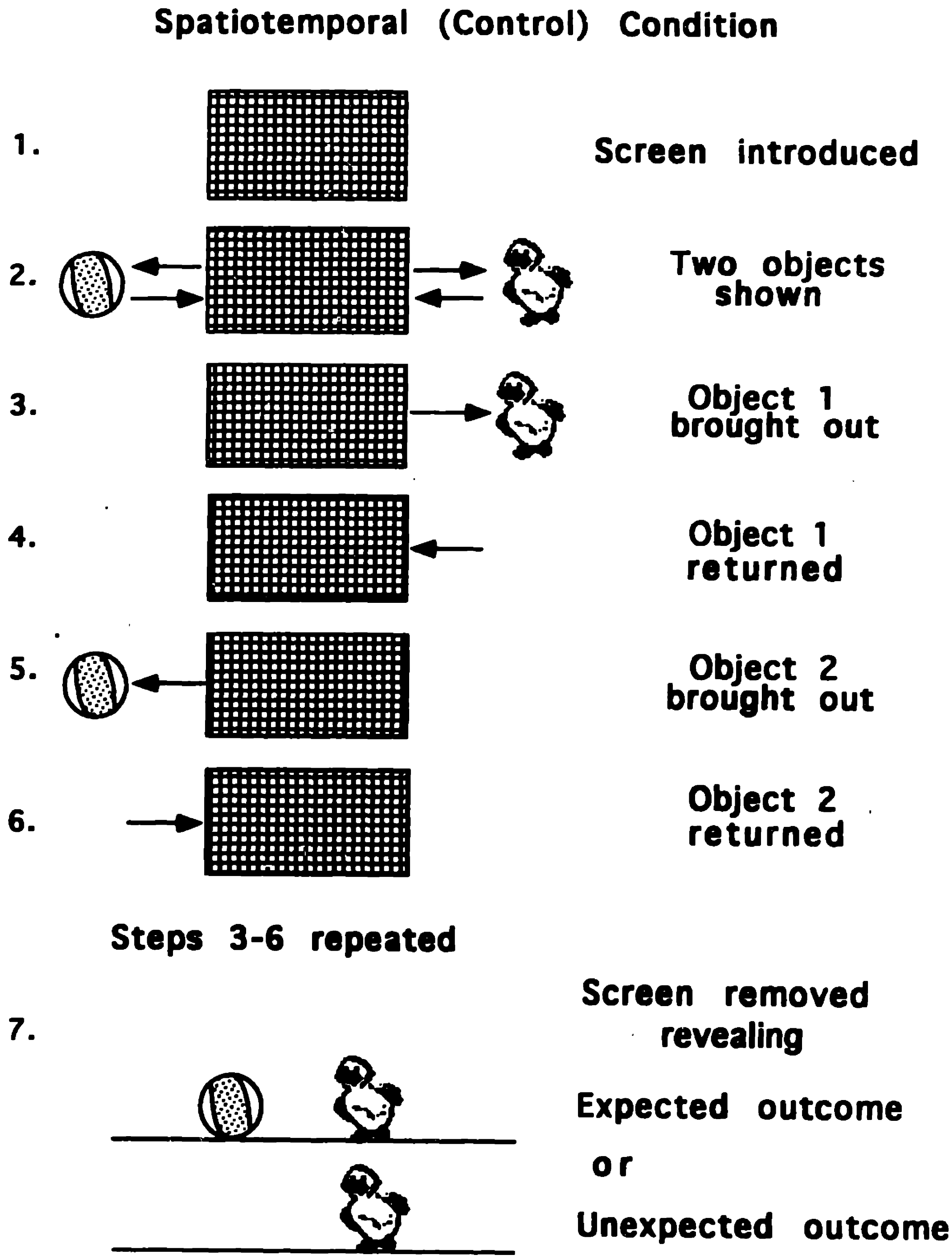

Spatiotemporal (Control) Condition
1.
Screen introduced
2.
Two objects shown
3.
Object 1 brought out
4.
Object 1 returned
5.
Object 2 brought out
6.
Object 2 returned
Steps 3-6 repeated
7.
Screen removed revealing
Expected outcome
or
Unexpected outcome

Figure 5

Chapter 2

Infants' Metaphysics: the Case of Numerical Identity*

Abstract

Adults conceptualize the world in terms of enduring physical objects. *Sortal concepts* provide conditions of individuation (establishing the boundaries of objects) and numerical identity (establishing whether an object is the *same one* as one encountered at some other time). In the adult conceptual system, there are two roughly hierarchical levels of object sortals. Most general is the sortal *bounded physical object* itself, for which spatiotemporal properties provide the criteria for individuation and identity. More specific sortals, such as *dog* or *car*, rely on additional types of properties to provide criteria for individuation and identity. We conjecture that young infants might represent only the general sortal, *object*, and construct more specific sortals later (the *Object*-first Hypothesis). This is closely related to Bower's (1974) conjecture that infants use spatiotemporal information to trace identity before they use property information. Five studies using the visual habituation paradigm were conducted to address the *Object*-first hypothesis. In these studies, 10-month-old infants were able to use spatiotemporal information but failed to use property/kind

----

* This research was supported by a grant from the NSF (BNS9012075) to Susan Carey. We would like to thank Alan Leslie and Elizabeth Spelke for very helpful discussion on the design of these experiments. We also thank Daphne Bavalier, Gavin Huntley, Susan Johnson, Scott Johnson, John J. Kim, Steven Pinker, Mary Potter, Sandeep Prasada, and especially, Ned Block, Paul Bloom, and Gary Marcus for helpful discussion and/or comments on an earlier draft of the paper. Thanks to Gary Marcus for suggesting the title of the paper. We thank R. Arriaga, B. Azad-Tatari, H. Bromberg, J. Choung, A. Ginzbursky, K. Raphaelidis, M. Schlaffer, J. Welch, A. Whitney, K. Wong, and especially, Laura Klatt for their assistance with subject recruitment and data collection. Finally we thank three reviewers for their very helpful comments. Correspondence should be addressed to Fei Xu, E10-106, Department of Brain and Cognitive Sciences, MIT, Cambridge, MA 02139, or e-mail to fei@psyche.mit.edu.

information to set up representations of numerically distinct individuals, thus providing empirical evidence for the *Object*-first Hypothesis. Finally, infants succeed at object individuation in terms of more specific sortals by 12 months. The relation between success at our task and early noun comprehension is discussed.

Adults conceptualize the world in terms of enduring physical objects. We have criteria for individuation of objects (telling where one ends and another begins) and for numerical identity (telling whether an object is the *same one* as one that we encountered earlier). As philosophers are at pains to point out, these criteria are part of our conceptual system; we *could* individuate and trace identity on the basis of different criteria, or we *could* have a conceptual system that contained no criteria for individuation or identity at all (see Hirsch, 1982, for a lucid discussion of logically possible conceptual systems that differ from ours in these respects). That this construction is far from inevitable raises the question of its origin; which aspects are innate, which constructed through interaction with various kinds of objects, and which constructed through language learning?

The philosophical literature has introduced the term "sortal" to denote a concept that provides criteria for individuation and identity (Wiggins, 1967, 1980; Gupta, 1980; Hirsch, 1982; Macnamara, 1987). In languages with the count/mass distinction, sortal concepts are lexicalized as count nouns. We cannot count without specifying what individuals to count. "How many are there in a pack of cards?", while syntactically well-formed, cannot receive a definite answer. The answer could be "fifty-two cards", "four suits of cards", or "billions of molecules". If we specify a sortal, "how many *cards* are there in a pack of cards", the answer becomes definite, "fifty-two." Similarly, we can only question numerical identity under a sortal. For example, a caterpillar turns into a butterfly. The answer to the question "is it the same *animal*" is "yes,", but the answer to the question "is it the same *caterpillar*" or "is it the same *bunch of molecules*" is "no."

There are a variety of criteria for individuation and tracing identity over time. In the case of ordinary physical objects, the most fundamental criteria are spatiotemporal. A single object cannot be in two places at the same time; and two objects cannot occupy the same space at the same time. Moreover, objects move on spatiotemporally continuous paths; if no continuous path exists between two appearances of what might be a single object or two distinct objects, we infer there must be two. Thus, *object*, in Spelke's (1988) sense of *bounded physical object*, is a sortal with spatiotemporal criteria for individuation and numerical identity.[1] For our everyday concepts such as *car, table,* or *person,* spatiotemporal continuity is not sufficient and additional criteria are called into play. To use an example from Hirsch (1982), imagine a junk car, consigned to the crusher. The process of crushing is spatiotemporally continuous. Yet we say that at a certain point the car goes out of existence, and is replaced by a lump of metal and plastic. When a person, Joe Shmoe, dies, Joe ceases to exist, even though Joe's body still exists. In both of these examples, a spatiotemporally continuous path could be traced throughout the process of crushing or death, but tracing identity under a sortal such as *car* or *person* leads us to override the spatiotemporal continuity and judge that the car or person ceases to exist at some point.

There is considerable evidence that infants as young as four months also represent the general sortal *object*. They use spatiotemporal information to establish representations of the individual objects in their immediate environment, and to trace identity through time (Spelke & Kestenbaum, 1986; Baillargeon, 1987; Spelke, 1988). To see how adults use such information, and to see what types of evidence show young infants to be like us in this regard,

---

1 Many philosophers claim that "object" is not a sortal term (Wiggins, 1980; Hirsch, 1982; Macnamara, 1987). We do not here claim that the sortal concept bounded physical object is expressed by the English word "object." We do claim, however, that bounded physical object functions as a sortal in the adult's conceptual system.

consider an experiment by Spelke & Kestenbaum (1986). Four-month-old infants were introduced to two screens, separated in space (see Figure 1 for a very similar design). They were shown an object emerging from the left hand edge of the left screen and then reemerging behind it. No object appeared in the space between the two screens. Then a physically identical object emerged from the right hand edge of the right screen, and then reemerged behind it. This sequence of events was repeated until the baby reached an habituation criterion, at which point the screens were removed revealing either two objects (expected outcome) or one object (unexpected outcome). Babies looked longer at the unexpected outcome, overcoming a baseline preference to look longer at two objects. Adults viewing the display also express surprise at the unexpected outcome of one object. Spelke & Kestenbaum conclude that babies (and adults) analyze the possible paths connecting the appearances of the objects, and infer from the spatiotemporal discontinuity that there must be two numerically distinct objects involved in the event.

At least two psychological theories of how sortals are learned have been proposed. Some have argued that the child's first sortal concepts are at the level of basic level kinds and establishing the gestalts for basic level kinds is the process of learning sortal concepts, i.e., once the child establishes a gestalt for dogs to the exclusion of cats and other categories, the child represents the sortal *dog* (Macnamara, 1987). Others, most notably Bower (1974), conjecture that babies use spatiotemporal criteria for individuating and tracing identity of objects well before they can use other property information. Although Bower was not concerned with what sortal concepts infants represent, his conjecture can be captured in our framework: infants may have the sortal *object* before they have other sortals more specific than *object*, e.g., *ball*. We will dub this "the *Object*-first Hypothesis."

Reflecting upon Bower's hypothesis, one may find it intuitive why *object* should have a privileged status: The spatiotemporal principles apply in the same way to all physical objects, but tracing identity under more specific sortals requires kind-relative information about types of objects and which of their properties change over time and which do not. For example, a size difference between observations at times 1 and 2 does not warrant an inference of two numerically distinct plants, but would warrant an inference of two numerically distinct chairs; a radical shape difference does not warrant an inference of two numerically distinct hands, but would warrant an inference of two numerically distinct toasters, and so on. Similarly, if we see a plant on the window sill and later a toy car at the same location, we infer two numerically distinct objects, for we know that plants do not turn into cars. It might serve the human baby well to use spatiotemporal information to individuate objects, and then slowly learn about the more specific kinds of individuals, and for each which properties change over time and which do not.

Although the hypothesis is plausible, Bower's attempts to address his conjecture were inconclusive. He examined infants' tracking of objects that disappeared behind screens. Of most relevance here are his studies in which the baby is habituated to one object (say a large, yellow, fuzzy rabbit) disappearing behind a screen (or into a tunnel) and then reemerging out the other side. After habituation, the baby is shown an event in which the object (the rabbit) goes behind the screen, but a different object (say a small, shiny, red ball) emerges from the other side. Bower claimed that 5-month-olds were surprised and that their looking behavior is disrupted, and he inferred that this was due to their realization that the object that emerged from behind the screen was different from the one that entered.

Others have failed to replicate this finding (Gratch, 1982; Meicler and Gratch, 1980; Muller and Aslin, 1978). These researchers found no disruption of tracking due to property differences between the objects at 5 months, 9 months, or even 18 months! However, failure to find a disruption of looking under these circumstances may simply reflect the power of a moving object to capture eye tracking. The baby may know that it's a new object, and that the original object must be somewhere else, but track it nonetheless. This is the reason for monitoring surprise as well as tracking behavior. Gratch (1982) found that 5-month-olds show no codable surprise when the object that emerged from the screen differed from the one that entered, but that 9-month-olds and 16-month-olds were surprised in this situation. Unfortunately, surprise does not establish that the child knows two numerically distinct objects are involved. The baby simply may be registering the differences in properties between the new entity and the entity they had been habituated to without inferring that there must be two entities. Baillargeon (1987) has established that babies expect objects to maintain their properties when out of sight. So the babies in Gratch's study may be evincing surprise that the rabbit-shaped object turned into a ball-shaped object, without inferring that there must be two distinct objects.[2]

---

[2] Another source of data potentially relevant to the question at hand derives from object permanence studies, in which on some trials the object hidden is surreptitiously replaced by a different object, so that when the baby retrieves it, it is not the one expected (e.g., LeCompte & Gratch, 1972). Two dependent measures -- surprise and whether the baby looks around for the other object -- were used. LeCompte & Gratch found that most 18-month-olds showed surprise, and they searched around the box. The 9-month-olds, on the other hand, showed mild puzzlement but did not search for the missing toy. The 12-month-olds' performance was intermediate in level: some acted like 18-month-olds and some like 9-month-olds. These results are inconclusive for the same reasons as Bower's studies: showing surprise may just mean that

What is needed is a sensitive methodology that can evaluate how many objects the infant represents in a certain event when given only property/kind information. In the present series of studies, we adapt Spelke & Kestenbaum's procedure and devise a variant of their procedure to address the hypothesis that infants may have the sortal *object* before other sortals more specific than *object*. We show babies events in which one object (say a rabbit) emerges from one side of a screen alternating with a different object (say a cup) emerging from the other side of the same screen. Adults infer from this display that there must be at least two objects behind the screen, since adults individuate and trace identity relative to sortals such as *rabbit* and *cup*. At issue is whether babies would make the same inference. The way to find out is to remove the screen, revealing either the two objects (expected outcome) or one (the rabbit *or* the cup; unexpected outcome). By the logic of the Spelke & Kestenbaum's study, if babies are able to use specific sortal membership or property information to establish representations of numerically distinct objects under these circumstances, they should look longer at the unexpected outcome.

Given Gratch's (1982) findings, we begin with 10-month-old babies. Our first task is to replicate Spelke & Kestenbaum's demonstration that babies use spatiotemporal information to trace the identity of objects under conditions similar to those we will use in our probes for the baby's use of property/kind information. Experiment 1 is a modified replication of Spelke & Kestenbaum's

the babies noticed the property differences but did not infer that it was a *different* toy; looking for the missing toy, on the other hand, may be too much to ask -- the babies might have realized that it was a different toy, but somehow decided not to look for the missing one, possibly because the new toy is of interest to them as a novel stimulus or maybe because they do not know where to look.

split screen procedure; Experiments 2-5 address the *Object*-first Hypothesis with the methodology sketched above.

Experiment 1

Experiment 1 seeks to confirm that 10-month-olds use spatiotemporal continuity to individuate and trace identity of objects over time. Spelke & Kestenbaum's split screen procedure was modified in two major ways. First, instead of a full habituation paradigm, babies were shown the critical events a fixed number of times. Second, Spelke & Kestenbaum's experiments used constantly moving objects; that is, after habituation, when the screens were removed, the objects (or object) revealed were in motion (i.e., oscillating). Spelke (personal communication) found this to be necessary for her results to obtain, perhaps because after extensive habituation, stationary objects would not hold very young infants' interest. Again, if the baby's understanding is robust, the results should hold whether the revealed objects are stationary or in motion.

Spelke & Kestenbaum's experiment contrasted the condition already described, where no object ever appeared in the space between the screens, with a condition in which an object traced a path continuously back and forth behind the screens, appearing in the middle. This controlled for any tendency to expect two objects for reasons unrelated to the path of the object(s) in the array (e.g., perhaps babies might expect two objects because there are two screens). In Spelke & Kestenbaum's findings, babies differentiated the continuous condition from the discontinuous ones, by treating the continuous events as indeterminate. That is, when the object appeared between the two screens, they did not reliably expect either one or two objects to be behind the screens. The babies are, strictly speaking, right -- the continuous events are consistent with any number of objects behind the screens. Experiment 1 includes a continuous condition for two reasons. First, it will serve as a control that will help establish the basis of the infant's preference in the discontinuous condition, and second, we will be able to see whether 10-month-olds make the simplest assumption that the continuous condition involves only one object.

Method

Subjects

Twenty-four full-term infants participated in the study (12 female and 12 male), age range from 9 months, 13 days to 10 months, 18 days (mean age 10 months, 3 days). Equal numbers of infants were in each of the two conditions (mean ages 10 months, 1 day, and 10 months, 5 days). Thirteen additional infants were excluded from the sample due to fussiness (7), experimenter error (1), or equipment failure (5). All infants were recruited by obtaining their birth records from town halls in the Greater Boston area and contacting their parents by mail.

Materials

One pair of identical yellow plastic cups was used in the baseline trials. Two pairs of toys were used in the test trials: two identical bright yellow toy ducks and two identical white foam balls. The toy ducks were about 8cm x 6cm x 4cm in size; the foam balls were about 6 cm in diameter. Four pairs of screens (11cm x 25cm each) of different colors, green, mauve, yellow, and lavender, were used.

Apparatus

The occlusion events were presented on a three-sided, 76 cm x 31 cm x 13 cm, puppet stage with a light blue top surface and a false bottom. A 70 cm track along which objects traveled was dug out in the middle of the stage; a slit in the back of the stage connected to the track was the route by which objects were taken out when necessary. A black curtain was hung at the back of the stage to make the object and background contrast prominent and to conceal the movement of the experimenter. Black curtains also concealed the observers, who sat on both sides of the stage and monitored when the babies were looking at the stage. The observers could not see what is presented on the stage and were blind to the condition the baby was in. Two push buttons were connected to an IBM-486 computer which recorded the amount of time an infant looked at each display. White noise masked any sounds produced by the movement of the experimenter throughout the experiment.

The stage was lit from above and from one side of the baby; otherwise the room was darkened. The baby sat in a high chair, 66 cm from the stage, facing the stage, with eye level slightly above (about 5 cm) the floor of the stage. The parent sat next to the baby with her/his back toward the stage. She or he was instructed not to look at the displays, so as not to influence the baby's response, and not to attempt to draw the baby's attention either toward or away from the stage. Her/his hand was on the edge of the high chair, and s/he was instructed to smile whenever the baby looked at her/him.

Design and Procedure

Equal numbers of infants participated in two conditions: continuous movement condition and discontinuous movement condition (See Figure 1 for schematic representations of the discontinuous condition).

Baseline/Introductory Trials. Both conditions had identical baseline or introductory trials. In these trials the experimenter tapped on the center and both ends of the stage to draw the baby's attention to the empty stage; only the experimenter's hand was visible to the infant. The experimenter then lowered two identical screens onto the center of the stage, 12 cm apart; the objects were lowered along with the screens but hidden behind them and invisible to the infant. When there were two objects involved, one object was placed behind each screen. The baby's attention was drawn (by tapping and hand waving) to each end of the stage, and to the empty space between the screens. No objects emerged from behind the screen. The experimenter then grasped the screens with both hands and turned them to the sides of the stage, revealing one cup or two cups standing still on the stage, about 15 cm apart. The screens stood next to the objects but not against the side walls of the stage. As the screens were being moved, the baby's attention was drawn, "Look at this, [baby's name,]"; the experimenter's hands were visible while removing the screens but her body was hidden behind the back curtain. The experimenter could not see the infant's face; if the infant did not look at the objects on stage, the primary observer would indicate that to the experimenter and the experimenter repeated "Look here, look, [baby's name]." The baby's looking at the cup(s) was monitored. One of the observers was designated the primary observer; a trial ended when the baby looked away for two consecutive seconds, as determined by the primary observer's button. At the end of the trial, the experimenter placed the screens back to their original position and removed the screens along with the objects hidden behind them. The baby's attention was then drawn to the empty stage, and the next trial began. Each baby saw one of two orders of outcomes: 2, 1, 1, 2 or 1, 2, 2, 1.

These baseline trials served two purposes. First, they showed the baby that in this event, there could be either one or two objects behind the two screens that were lowered onto an empty stage. Second, they provided a baseline for each baby's preference for looking at displays consisting of one vs. two objects. Of course, they provided the baby with no way of predicting which outcome would occur in the test trials.

Test Trials. Discontinuous Movement Condition. Two pairs of test trials followed the baseline/introductory trials. Each test trial contained two phases, a familiarization and a test phase.

Every test trial began by drawing the child's attention to the empty stage, lowering two screens onto the stage, and drawing the child's attention to the empty space between them. The manner in which these steps were carried out was identical to that of the baseline trials. During the familiarization event, objects emerged from behind the screen, traveling on the track. All object movement was controlled by the experimenter holding a stick on the bottom of each object that protruded through the track. About 0.5 cm of the stick was visible to the infant as the object moved; no noise was associated with the movement. One object started from behind one of the screens, moved to one end of the stage, tapped for 3 or 4 times to draw the infant's attention, "Look here, [baby's name]", and then back to its original position. After roughly a 2 second pause (the same amount of time for an object to travel through the intervening space), a second object, emerged from behind the second screen, moved along the track to the opposite end of the stage, tapped for 3 or 4 times to draw the infant's attention, and then back to its original position. From the infant's point of view, no object ever appeared between the two screens. In all events, the objects moved at a constant speed of about 8 cm/sec.

Insert Figure 1 about here.

The baby observed two emergences to one side and two to the other, alternating between the two sides and then on the fourth emergence the object was left in full view and the baby's looking monitored. This ensured that infants realized that sometimes these objects could be stationary. After the baby looked away (as determined by the primary observer's push button), the object was returned behind the screen, and a total of four more emergences and returns were presented. Thus, the baby saw the object emerge from the left screen a total of four times and from the right screen a total of four times and never saw any object move from the left to the right screen through the middle space or vice versa. After this familiarization event, the experimenter grasped the screens and turned them to the sides of the stage, revealing one object (unexpected outcome) or two objects (expected outcome). During the whole experiment, only the experimenter's hands were visible to the infant; her body was hidden behind the back curtain. In case of the unexpected outcome trials, the experimenter swiftly and quietly removed one of the objects right before the removal of the screens; the timing was such that the pause in between the last emergence and the removal of the screens for both expected and unexpected outcomes was identical. Looking time was monitored after the screens were removed, and when the baby had looked away for two consecutive seconds, the trial ended and all screens and objects were removed. A second trial ensued with the opposite outcome using a different pair of screens but the same toys. It was exactly the same as the above, except that the infant had only four exposures to the objects before the screens were removed, instead of eight. Pilot testing suggested that eight more trials were too boring and babies became fussy. This second set of 4 familiarization emergences from the screen did not include one in which the object was left stationary.

A second pair of trials using the second pair of toys followed. The procedure was identical to that of the first pair (i.e., 8 emergences for first trial, including one in which the object was left stationary; 4 emergence familiarization for second trial).

The order of pairs of toys (ducks first, foam balls first), order of outcomes (expected, unexpected, unexpected, expected or unexpected, expected, expected, unexpected), and side on which the single object appeared (left, right) were counterbalanced across subjects.

Test Trials. Continuous Movement Condition.. The continuous condition was identical to the discontinuous condition except that only one object was used in the familiarization emergences and it moved back and forth along the whole track, appearing in the space between the screens.

Different color screens were used for all baseline and test trials; the order of the screens was determined in a quasi-random manner. No two consecutive trials used the same screens; the different colors were used to attract the baby's attention. One might worry that the observers could tell from the infant's eye movement whether there were one or two objects on the stage. However pilot testing revealed that observers simply could not tell, because infants move their eyes back and forth in both one- and two-object trials. This may be due to the fact that infants were searching for the second object or because screens were left on both sides of the stage so the infant does have something to look at on both sides of the stage. One may also query whether the observer could tell which condition (discontinuous vs. continuous) the infant was in. Pilot testing showed that infants turned their heads to track objects in both the discontinuous and continuous conditions and it was impossible to tell whether an object appeared in the middle.

Nine of the 24 babies were observed by two observers. Inter observer reliability was modest (83%) because many of these sessions were training sessions for the second observer. The primary observers had been trained in other studies; an observer is considered trained when he or she attains interscorer reliability with a trained primary observer for an average of 95% on three consecutive babies.[3]

Results

Figure 2 presents the mean looking times for each condition.[4]

---

[3] In Experiments 3-5, we introduced videotaping of babies' looking so that subjects can be offline observed completely blindly. For all of these experiments, interscorer reliability was over 90%. Sometimes the observers could tell which experiment or condition the baby was in because of the procedure, but they were completely blind to the order of outcomes. In all experiments, observers reported that they could not guess whether the babies were looking at one object or two object outcomes. For Expts. 4 & 5, the videotape observers were asked to guess which order of outcome (1, 2 or 2, 1) each baby was in. For all 49 babies videotaped, the observers guessed correctly 26 of them, which was chance performance.

[4] Within each condition in this experiment and all subsequent experiments, initial ANOVAs examined the influence of gender, order of outcomes (1,2,2,1 or 2,1,1,2), order of object (duck first, ball first), side of single outcome (left, right). Except for one case, there were no statistical effects of gender, order of object, order of outcomes, or side of single outcome. However, given the small number of subjects, these non-effects are not particularly meaningful.

Insert Figure 2 about here.

Consider first the baseline/introductory trials, which were identical in both conditions. Recall that these trials involved lowering two screens onto the stage and then turning them to the side revealing either one object behind one of them or two objects (one behind each). Babies did not differentiate outcomes of one vs. two objects on the baseline trials of either condition, nor did looking times in the baseline trials differ in the two conditions. In the discontinuous condition, 8 out of 12 babies looked longer at 2 objects in the baseline trials; in the continuous condition, 6 out of 12 babies looked longer at 2 objects in the baseline trials.

Separate ANOVAs for each condition compared the pattern of looking on baseline and test trials. In the Discontinuous Condition, there was a main effect of trial type ($F(1,11) = 35.33$, $p < .001$). Babies looked reliably longer on the test trials (8.4 sec.) than on the baseline trials (4.3 sec.). Most importantly, the interaction between trial type (baseline vs. test) and outcome (1 vs. 2 objects) was significant, $F(1,11) = 8.58$, $p < .02$. Babies looked longer at outcomes of one object on the test trials ($M_{one-obj.} = 9.3s$, $SD = 4.5$; $M_{two-obj.} = 7.5s$, $SD = 4.9$), but not the baseline trials ($M_{one-obj.} = 3.8s$, $SD = 2.6$; $M_{two-obj.} = 4.7s$, $SD = 3.2$; see Figure 2). That is, babies looked longer at what for adults would be the unexpected outcome. The looking preference for one object on the test trials was itself significant ($F(1,11) = 4.97$, $p < .05$). Non-parametric analyses revealed the same pattern. Nine of 12 babies differentiated the outcomes on the test trials (i.e., looking longer at one-object displays) more than on the baseline trials (Wilcoxin

T = 12, $p < .03$, one-tailed). On the test trials only, 9 of 12 babies showed a preference for one-object outcomes (Wilcoxin T = 10, $p < .03$, one-tailed). Infants looked longer at the one-object outcomes for both pairs of test trials: first pair: Mone-obj. = 9.1s, Mtwo-obj. = 7.7s; second pair: Mone-obj. = 9.3s, Mtwo-obj. = 7.2s.

An ANOVA of looking times in the Continuous Condition with trial type (baseline vs. test) and outcome (1 vs. 2 objects) as factors revealed no main effect of trial type or outcome. The interaction between trial type and outcome on looking times for the test trials was significant ($F(1,11) = 6.74$, $p < .03$). This interaction was due to the babies differentiating the outcomes on the test trials, but not on the baseline trials. In this condition, babies looked longer at outcomes of *two* objects on the test trials, again, looking longer at what for adults would be the unexpected outcome. The looking preference for two objects on the test trials was itself marginally significant ($F(1,11) = 4.42$, $p < .06$). Non-parametric analyses revealed the following pattern: on the test trials alone, 9 of 12 babies preferred two-object outcomes (Wilcoxin T = 14, $p < .05$, one-tailed). Seven of 12 babies showed more differentiation on the test trials than on the baseline trials (Wilcoxin T = 22, $p > .1$, one-tailed). Infants looked longer at the two-object outcomes for both pairs of test trials: first pair: Mone-obj. = 5.9s, Mtwo-obj. = 8.4s; second pair: Mone-obj. = 5.3s, Mtwo-obj. = 6.9s.

Finally, an analysis of variance examined the effects of condition (discontinuous vs. continuous) and outcome (1 vs. 2 objects) on the test trials. The interaction between condition and outcome was significant ($F(1,22) = 9.25$, $p < .006$). This further confirms that the infants were influenced by whether the familiarization events they saw involved continuous or discontinuous motion.

Discussion

Infants interpreted the discontinuous event as involving two objects, and looked longer at the unexpected outcome of one object. Just like adults, 10-month-old infants use spatiotemporal information to establish how many individuals are involved in an event, and to track identity of those individuals over time. They understand that objects travel on continuous paths; no object can jump from one point in space to another without passing through the intervening space. These data replicate the pattern of results Spelke & Kestenbaum obtained with younger infants. At 10-months, a relatively brief familiarization exposure to the discontinuous motion suffices, and at 10-months, babies differentiate the expected and unexpected outcomes even when the objects are stationary.

Spelke & Kestenbaum's younger infants interpreted the continuous event as indeterminate with respect to whether one or two objects were involved, and the 10-month-olds in Experiment 1 seem to have done the same. Although the interaction between the baseline and test trials was significant, only 7 of the 12 babies showed a stronger preference for two objects on the test trials than on the baseline trials. Furthermore, the longer looking at two objects may reflect a familiarity effect as opposed to an expectancy of one object: the babies have been shown one object over and over again, they may simply find the two-object outcome novel and more interesting to look at. Of course, the continuous event *is* actually indeterminate; it is compatible with there being one or more than one object behind the screen.

Experiment 1 confirms that 10-month-olds' have the sortal concept *object.* Their capability of analyzing spatiotemporal information for evidence of how many objects are involved in events such as these is quite robust, and can be demonstrated in the familiarization version of Spelke & Kestenbaum's procedure. This sets the stage for the studies that are our main focus, those concerning the infants' ability to trace identity under sortals more specific than *object*.

Experiment 2

Experiment 2 was closely modeled on Experiment 1, with two critical differences. First, a single screen was involved in each trial. Second, the baby was familiarized with two very different objects (e.g., a toy duck and a foam ball) emerging alternately from each side of the screen. The objects in each pair differed in texture, shape, and color, as well as in kind. Adults draw the inference from the property/kind differences that there must be at least two objects behind the screen. The question is whether 10-month-old babies will similarly conclude that there must be two numerically distinct objects behind the screen.

Experiment 2 also included a condition in which babies were provided spatiotemporal information that two distinct objects were involved in the test event. At the beginning of each set of familiarization emergences, both objects were moved to each side of the screen, simultaneously visible, and the babies' attention was drawn to them. In this condition babies had both spatiotemporal and property/kind information available in their interpretation of the familiarization events.

A third condition in Experiment 2 was a baseline condition in which babies saw the same introductory trials followed by the outcomes of the test trials without any familiarization emergences. This condition provided us with an estimation of whether there was any intrinsic preference for looking at one- or two-object displays.

Method

Subjects

Forty-eight full-term infants participated in the study (24 male and 24 female) with a mean age of 10 months, 2 days (ranged from 9 months, 12 days to 10 months, 18 days). Equal numbers of infants (16) participated in each condition (mean ages 9 months 28 days, 10 months 3 days, and 10 months 2 days). The infants were recruited from the Greater Boston area as in Experiment 1. Eight additional infants were eliminated from the experiment due to fussiness (5) or equipment failure (3).

Materials and Apparatus

The same puppet stage as in Experiment 1 was used in Experiment 2. Four foam board screens (34 cm x 25 cm each) of different colors (green, yellow, lavender, and mauve) were used. The single screen was the same width as the two screens plus the gap between them in Experiment 1.

Six different toys were used in this experiment. A yellow plastic cup and a brown toy camel were used in the introductory trials. Two pairs of toys, a white foam ball and a yellow rubber toy duck, and a bright red toy truck and a light blue rubber toy elephant, were used for the test trials. The toy duck and ball were the same ones that were used in Expt. 1. The toy truck was about 12 cm x 4 cm x 4 cm in size; the toy elephant was about 8 cm x 6 cm x 4 cm in size.

Design and Procedure

Introductory Trials. As in Experiment 1, babies in all three conditions began with four introductory trials where they were introduced to the experiment: babies learned that there were objects behind the lowered screens, sometimes one and sometimes two. Again, these introductory trials provided no information as to how many objects would be present when the screen was removed in the test trials.

In each introductory trial, an experimenter hiding behind the black backdrop lowered a screen onto the empty stage, and then she turned the screen to the side revealing either one object (a cup or a camel) or two objects (the cup and the camel). In this and other parts of the experiment, only the experimenter's hands were visible to the infant. The experimenter had a top view of the stage such that she could not see the infant's face. Two orders of outcomes (1,2,2,1 and 2,1,1,2), and the order of the single object (cup, camel; camel, cup) were counterbalanced across subjects.

The same recording procedure was used as in Experiment 1. Only one very experienced observer observed each baby in this experiment (but see Expt. 3-5 for replications). The observer did not know which order of outcome (expected first or unexpected first) the baby was shown.

Property/Kind Condition. Experiment 2 was closely modeled on Experiment 1 (Figure 3.1). An experimenter tapped on both ends of the stage to draw the baby's attention to the empty stage, and a screen with two toys concealed behind it was lowered onto the stage. The screen was lowered at exactly the same position on the stage as were the two screens in Experiment 1. One toy was moved from behind the screen to its left and returned behind the screen; the other toy was then moved from behind the screen to its right and then returned behind the screen. The number, structure, and timing of the familiarization emergences were exactly as in Experiment 1. The first set involved four emergences of each toy, one toy being left stationary in view on the fourth emergence. After the familiarization emergences, the screen was removed to the side, revealing either two objects (expected outcome) or one object (unexpected outcome). After the first trial, the stage was cleared, and a new screen concealing the same two toys was lowered. The second trial with this set of toys involved two familiarization emergences to each side before the screen was removed to reveal the opposite outcome of the first trial. The whole procedure was then repeated with the second pair of toys. The order of toy pairs (duck/ball vs. elephant/truck), the order of outcomes (1, 2, 2, 1 or 2, 1, 1, 2), and which toy was the single outcome were counterbalanced across subjects.

Insert Figure 3.1 about here.

Spatiotemporal Condition. The spatiotemporal condition was identical to the property/kind condition except for one difference. The infants saw the same introductory trials involving the cup and the camel. But before each set of familiarization emergences for the test trials, with the screen standing on stage, the experimenter brought out the two objects from behind the screen simultaneously, one to each side of the screen, tapped them on the stage for about 3 seconds, the baby's attention drawn to them, and then returned the objects behind the screen. The procedure then unfolded exactly as on the test trials of the property/kind condition.

Insert Figure 3.2 about here.

Baseline Condition. The baseline condition also had the same introductory trials. Following these, the infants were simply shown the outcomes of the test trials of the other two conditions without any familiarization emergences, e.g., a screen was lowered then turned to the side, showing either one or two objects behind it. The baseline condition provides a measure of the infants' intrinsic preference for looking at one-object vs. two-object displays with the same objects used in the test trials.

Results

Introductory Trials. The introductory trials were identical in all three conditions. An ANOVA examined the effects of number of objects (1 vs. 2) and condition (baseline, property/kind, spatiotemporal) on looking times. There was no main effect of number of objects, nor an interaction between number of objects and condition. In the introductory trials, infants showed no preference for looking at the outcome of one (M = 5.4s) or two objects (M = 6.2s). There was, however, a main effect of condition ($F(2, 45) = 3.955$, $p < .03$). Posthoc ANOVAs employing the Bonferroni procedure revealed that this was due to the infants in the spatiotemporal condition (M = 4.4s) looking less than those in the baseline condition (M = 6.7s) and the property/kind condition (M = 6.2s). Since these trials were identical in all conditions, this effect must reflect random sampling differences among the groups.

Test Trials. The principal findings are shown in Figure 4, where the baseline trials were compared with the test trials of the property/kind condition and the spatiotemporal condition.

Insert Figure 4 about here.

As Figure 4 shows, the main result of this study is that the infants had a strong preference for two objects in the baseline, and they failed to overcome this preference in the property/kind condition but succeeded in the spatiotemporal condition.

Property/Kind Condition. Looking times in the property/kind condition were compared with that of the baseline in an ANOVA with condition (baseline vs. property/kind) and outcome (one vs. two objects) as variables. There was a main effect of number; overall infants looked longer at two-object displays ($F(1,30) = 14.55$, $p < .001$). More importantly, the looking time pattern for the property/kind condition did not differ from that of the baseline ($F(1,30) = .098$, $p = .756$; Baseline: Mone-obj. = 8.3s, SD = 3.8; Mtwo-obj. = 11.7s, SD = 5.4; Prop/Kind: Mone-obj. = 7.3s, SD = 2.2; Mtwo-obj. = 10.3s, SD = 3.1). That is, the infants did not look longer at the unexpected outcome of one object in the property/kind condition. Remember that there were two sets of test trials, first with one pair of objects and then a second pair of objects. There was no effect of trial pair; the looking preference for two object outcomes was equally strong on the second pair of objects as on the first pair of objects (Trial pair 1: Mone-obj. = 7.7s, Mtwo-obj. = 10.9s; Trial pair 2: Mone-obj. = 7.0s, Mtwo-obj. = 9.6s). Planned t-tests on each condition alone showed main effects of number in both conditions (Baseline: $F(1,15) = 4.708$, $p < .05$; Property/kind Condition: $F(1,15) = 32.204$, $p < .0001$). The strong baseline preference for two objects showed that the infants had to overcome this strong bias in order to succeed in any version of this task. There was not even a hint in the data that their preference was reduced in the test trials of the property/kind condition.

Individual data confirmed the above results. Twelve of the 16 infants in the baseline condition looked longer at outcomes of two objects and 15 of the 16 infants in the property/kind condition showed the same preference on the test trials.

Spatiotemporal Condition. A very different pattern of results emerged when we compared the spatiotemporal test trials and the baseline (see Figure 4); looking preferences for outcomes of one or two objects were clearly influenced by whether or not both objects were seen simultaneously before the familiarization emergences began. An ANOVA examining the effects of condition (baseline vs. spatiotemporal) and outcome (one vs. two objects) on looking times revealed a main effect of condition ($F(1,30) = 10.90$, $p < .002$); infants looked overall longer in the baseline condition (M = 10.0s) than in the spatiotemporal condition (M = 6.7s). Recall that the same difference was seen on the introductory trials. There was also a marginally significant effect of number ($F(1,30) = 4.08$, $p = .053$). More importantly, there was an interaction between condition and number of objects ($F(1,30) = 4.71$, $p < .05$; Spatiotemporal: Mone-obj. = 6.7s, SD = 2.8; Mtwo-obj. = 6.8s, SD = 2.2). That is, although there was no overall looking preference for one object on the test trials (the unexpected outcome), the interaction between the two conditions showed that the looking time pattern in the spatiotemporal condition was significantly different from that of the baseline. The looking preference for each test trial pair was as follows: Trial pair 1: Mone-obj. = 7.2 s, Mtwo-obj. = 7.5 s; Trial pair 2: Mone-obj. = 6.1 s, Mtwo-obj.= 5.9 s.

Non-parametric analyses confirmed that infants in the spatiotemporal condition were able to overcome a baseline preference for two objects. Twelve out of 16 infants looked longer at two-object outcomes in the baseline condition; in contrast, only 5 of the 16 infants in the spatiotemporal condition looked longer at outcomes of two objects (c2(1) = 4.52, p < .04).

A third ANOVA compared patterns of looking times on the test trials of the property/kind condition and the spatiotemporal condition with condition and outcome (1 vs. 2 objects) as variables. There was a main effect of condition; babies looked longer at the test trials in the property/kind condition (M = 8.8 sec.) than in the spatiotemporal condition (M = 6.7 sec.; F(1,30) = 6.87, p < .02). Recall that this difference was also seen on the introductory trials. Overall there was a main effect of number (F(1,30) = 10.98, p < .002); babies looked longer at two objects. Most importantly, there was an interaction between condition and outcome (F(1,30) = 9.53, p < .004). Only the babies in the property/kind condition looked longer at outcomes of two objects. The difference between the two conditions was further revealed by non-parametric analyses; 15 of the 16 babies in the property/kind condition looked longer at outcomes of two objects whereas only 5 of the 16 babies in the spatiotemporal condition looked longer at outcomes of two objects (c2(1) = 10.80, p < .001).

All of the babies in this study were observed by a single, highly trained observer. There are three reasons to be confident in these results, in spite of the fact that there was only one observer. First, the observer was blind to the order of the outcomes, and reported that she did not know which order the infant was in. Second, the results were the opposite of what we expected (we expected babies to succeed at this task), so it is unlikely that unconscious experimenter or observer bias could have influenced the results. Finally, in Experiments 3-5, we replicate these results in a new setup in which we videotape the baby's looking and report interscorer reliability between the primary observer and the videotapes that are scored blind.

Discussion

Given that the babies had a strong preference for two object displays, success at this task is not looking longer at the unexpected outcome of one object, but rather overcoming the baseline preference. The major result of this experiment is the failure of 10-month-old infants in the property/kind condition to do so. Rather, they did not show a different looking pattern compared to the baseline preference of looking longer at two objects. In this experiment, babies failed to demonstrate that they could use the differences between a yellow rubber toy duck emerging from one side of the screen and a white Styrofoam ball emerging from the other side of the screen to infer that there must be at least two objects behind the screen. And they equally failed to demonstrate the ability to use the differences between a bright red metal toy truck and a light blue rubber toy elephant to infer that there must be two objects behind the screen. As we try to interpret this result, we must remember that babies of this age succeeded at using two types of spatiotemporal information, i.e., the spatiotemporal information provided by discontinuous path in Experiment 1 and the spatiotemporal information provided by seeing the two objects simultaneously in Experiment 2, when provided the *same* number of familiarization emergences, and where success was measured by the *same* outcome variable. Thus, these data are consistent with the *Object*-first Hypothesis: 10-month-old infants represent one sortal concept, *object*, but not the more specific sortal concepts probed in this study (*duck, ball, truck,* and *elephant*). These data are also consistent with Bower's conjecture: babies use spatiotemporal information to individuate and trace identity of objects over time before they use property/kind information. However, these data do not support Bower's contention that property/kind information can be exploited for object individuation and identity tracing by 5 months of age; under the conditions of this experiment, at least, even 10-month-olds failed to do so.

The infants showed a strong intrinsic preference for two objects in the baseline of Expt. 2. In contrast, the infants in Expt. 1 did not show particular preference for outcomes of one cup or two cups in the baseline trials. The difference between the two experiments lies in the fact that in Expt. 2, single object displays (e.g., a ball) are contrasted with double object displays of two very different objects (e.g., a ball and a duck). Apparently, infants found a duck and a ball much more interesting to look at than just a ball or a duck.[5]

One might argue that the strong intrinsic preference for looking longer at two objects, as shown by the baseline data, may have swamped the effect of infant's expectation for two objects. This possibility is unlikely because despite the intrinsic preference for two objects, infants in the spatiotemporal condition nonetheless showed success. That is, when given spatiotemporal information,

---

[5] Readers may wonder why there was no preference for two object displays (a camel and a cup) over one object displays (just a camel, or just a cup) on the introductory trials of Expt. 2. We think that the properties of these two objects were not as distinct as the other objects we used. Since they were different objects from the ones used in the test trials, they did not provide a proper baseline. Hence a baseline condition was needed.

10-month-old infants were able to overcome their preference for two objects and exhibited a different pattern of looking compared to their baseline.

Although the looking preferences of the babies in the spatiotemporal condition differed from the baseline, these babies in the spatiotemporal condition did not look overall longer at the unexpected outcome (see Figure 4); rather they looked about equally at outcomes of one and two objects. It seems plausible that given the strong intrinsic preference to two-object displays shown in the baseline, infants may not be able to completely override that tendency. It is also possible, however, that the infants construed the back and forth pattern of emergences as providing positive spatiotemporal evidence for a single object, much in the same manner of the continuous trajectory of Experiment 1. Thus the spatiotemporal condition of Experiment 2 may pit two sources of spatiotemporal information against each other and these two sources of information canceled each other. We think that the first possibility (strong baseline preference for two) is more likely, but in Experiment 3 we attempt to break the illusion of a single oscillating motion by leaving the objects in view for the baby to habituate to during the familiarization emergences.

Readers may recall that overall the infants in the spatiotemporal information looked less than infants in the other two conditions. This is worrisome because it is possible that the reason infants succeeded in the spatiotemporal condition is not because they had the spatiotemporal information but rather it was because this particular group of babies were fast encoders (Columbo, Mitchell, & Horowitz, 1988). And the fact that we did not use a full habituation paradigm raises the possibility that 10-month-olds may be able to use property/kind information to infer identity change but just not as efficiently as using the spatiotemporal information. These questions will be taken up in Expts. 3 & 4, respectively.

One last concern is that babies apparently failed to use property/kind differences to infer there must be two objects, but perhaps they did not *notice* the property differences. Babies' performance in the property/kind condition was consistent with the following representation of the familiarization events: an object emerges from left and returns behind the screen; an object emerges from right and returns behind the screen, etc. In this representation, there is no further specification of object properties or kind. We find this an unlikely possibility, given evidence that babies even much younger than these habituate to objects that share salient properties, and dishabituate when presented an object that differs with respect to these properties (e.g., Cohen and Younger, 1983). However, it is important for us to show that under the circumstances of our experiments, infants encode the properties of the objects. This question is addressed directly in Experiment 3.

Experiment 3

Experiment 3 addresses several questions raised by Experiment 2. First, given the amount of exposure during familiarization, perhaps babies did not even notice the property/kind differences between the two objects, in which case they certainly could not infer from these differences that there were two objects behind the screen. In Experiment 3, objects were left stationary in full view for a total of four times during familiarization emergences, providing ample opportunities for the infants to encode their properties. The infants were allowed to look at these objects for as long as they desired. This manipulation will also bear on the possibility that infants in Expt. 2 may have taken the oscillating motion as *positive* evidence that there was only one object, for leaving the objects stationary breaks the regular oscillation. Finally, the possibility that the property differences between the objects might be having at least some effect on object individuation will be addressed through a comparison with a condition where a single object emerged from both sides of the screen.

Method

Subjects

Thirty-two full-term 10-month-old infants (14 male and 18 female) were randomly assigned to the Different Condition (mean age of 10 months, 1 day; range from 9 months, 15 days to 10 months, 13 days) or to the Same Condition (mean age of 9 months, 29 days; range from 9 months, 13 days to 10 months, 16 days). The baseline from Expt. 2 served as the baseline for the Different Condition. A group of 16 infants (7 male and 9 female) was assigned to the baseline condition for the Same Condition (mean age 10 months, 7 days; range from 9 months, 23 days to 10 months, 17 days). All infants were recruited from the Greater Boston area as in previous experiments.

Materials and Apparatus

The toys used were exactly the same as in Experiment 2. The stage was the same one as in Experiment 2. Additionally, a video camera was set up under the stage, focusing on the baby's face. The videotape record provides no information about what is presented on the stage so an observer scoring from the videotapes will be completely blind to the condition or the order of the trials.

Design and Procedure

Equal numbers of infants participated in four conditions: the Different Condition (or the "duck-ball" condition) and its baseline (the "duck-ball" baseline), and the Same Condition (or the "duck-duck" condition) and its baseline (the "duck-duck" baseline). Four introductory trials preceded test trials in all four conditions. In the Different Condition and its baseline condition, the introductory trials were the same as in Experiment 2 using a cup and a toy camel; in the Same Condition and its baseline condition, one or two identical cups were shown in the order of 1, 2, 2, 1 or 2, 1, 1, 2.

Different (or "duck-ball") Condition. The procedure for the Different Condition was the same as in the Property/Kind condition in Experiment 2 with one important modification. During the familiarization emergences (preceding the first removal of the screen on the test trials), the infants saw a total of 10 emergences of the pair of toys alternating on two sides of the screen. On the 3rd and 4th, and 7th and 8th emergences, the object was left stationary on the side of the stage and looking time was monitored. That is, the infants saw each object twice standing stationary. This modification serves several purposes. One is that the looking times we record during the familiarization event, when compared with the counterpart in the Same Condition, will tell us whether the infants have noticed the perceptual differences between the duck and the ball. A second is that leaving the objects out for the babies to look at until they are bored will, to a certain extent, break the illusion of a single oscillating trajectory. Finally, this modification provides the infant more time to encode the properties of the two different objects.

Different (or "duck-ball ")Baseline. The baseline for the Different Condition was taken from Expt. 2. After the four introductory trials, the baby was shown the outcomes of the test trials without any familiarization emergences, e.g., a screen was lowered with the objects concealed behind it, then removed to the side to reveal the objects, say a duck and a ball.

Same (or "duck-duck") Condition. The procedure for the Same Condition was the same as that in the Different Condition with one major difference: instead of using two very different objects for each pair of toys, two identical objects were used, i.e. two identical toy ducks, two identical balls, two identical toy elephants, and two identical toy trucks. Half of the babies saw a pair of ducks and a pair of balls; half of the babies saw a pair of elephants and a pair of trucks.

Same (or "duck-duck") Baseline. The infants in this condition were shown the same introductory trials as in the Same Condition, followed by just the outcomes of the test trials of the Same Condition without any familiarization emergences, e.g., a screen was lowered with the objects concealed behind it, then removed to the side to reveal the objects, say two identical ducks.

Results

Introductory Trials. An ANOVA examined the introductory trials of the Different Condition and its baseline with condition (different vs. baseline) and outcome (1 vs. 2 objects) as variables. There were neither main effects of condition or outcome nor an interaction between the two factors. That is, infants did not look longer at either one object or two objects and the baseline infants did not differ from the infants in the Different condition. A similar ANOVA examined the introductory trials of the Same Condition and its baseline with condition and outcome as variables. Again, there were no main effects or interactions between these variables.

Habituation Trials. During the familiarization emergences, each object was left stationary twice for the baby to look at until s/he turned away, yielding four habituation trials. An ANOVA examined the effects of trial (1 vs. 2 vs. 3 vs. 4) and condition (Different vs. Same) on these looking time measures (Figure 5). There was an interaction between the two factors, $F(3, 90) = 2.886$, $p < .04$. This interaction was due to there being no effect of trial number in the Different Condition, contrasted with a significant decrease in looking times between trial 1 and trial 2 in the Same Condition. In sum, babies who saw the sequence duck, duck, duck, duck showed significant habituation over the familiarization emergences, whereas babies who saw the sequence duck, ball, duck, ball did not. We conclude that babies in the Different Condition noticed the differences between the two objects of each pair.

Insert Figure 5 about here.

Even though the infants noticed the property differences, the question of interest is whether these property differences had any impact at all on infants' inference of how many objects were behind the screen. This was analyzed by a comparison of the test trials with the baseline condition (Figure 6).

Insert Figure 6 about here.

Different (or "duck-ball") Condition Test Trials and its Baseline. Baseline: An ANOVA examined the effect of number, and found a strong preference for looking longer at two-object displays ($F(1,15) = 4.708$, $p < .05$). Twelve of the 16 infants exhibited this preference.

Different Condition: An ANOVA was performed with type of trial (baseline vs. test) and outcome (1 vs. 2) as variables. There was a main effect of number ($F(1,30) = 11.111$, $p < .002$). Infants looked longer at two-object displays (M = 10.5s) than one-object displays (M = 7.3s). There was no interaction between the two factors ($F(1, 30) = .066$, $p = .80$; Test: Mone-obj. = 6.4s, SD = 2.7; Mtwo-obj. = 9.4s, SD = 5.4). Thirteen of the 16 infants looked longer at two-object outcomes on the test trials. In sum, the infants did not exhibit a pattern of data on the test trials that were different from the baseline preference for two objects.

Same ("duck-duck") Condition Test Trials and its Baseline. Baseline: An ANOVA examined the effects of number. There was no main effects of number. Nine of the 16 infants looked longer at two-object outcomes.

Same Condition: An ANOVA was carried out with type of trial (baseline vs. test) and outcome (1 vs. 2) as variables. There was a main effect of type ($F(1, 30) = 9.222$, $p < .005$) as well as a main effect of number ($F(1, 30) = 4.522$, $p < .05$). Infants looked longer on the baseline trials (M = 10.8s) than the test trials (M = 6.0s); they also looked longer at two-object displays (M = 9.1s) than one-object displays (M = 7.7s). There was no interaction between type of trial and outcome ($F(1, 30) = 1.816$, $p = .188$; Baseline: Mone-obj. = 10.6s, SD = 6.5; Mtwo-obj. = 11.1s, SD = 6.5; Test: Mone-obj. = 4.8s, SD = 1.8; Mtwo-obj. = 7.1s, SD = 2.8). That is, the infants' preference for two-object outcomes on the test trials did not differ significantly from the baseline preference. However, since there was no reliable difference on the baseline trials, an ANOVA with outcome (1 vs. 2) as factor was carried out with the test trials alone. There was a main effect of outcome, $F(1,15) = 9.372$, $p < .01$. Thirteen of the 16 infants preferred two-object outcomes on the test trials.

Finally a three-way analysis of variance was performed with condition (different vs. same), type of trial (baseline vs. test) and outcome (1 vs. 2 objects) as variables. There was a main effect of number ($F(1, 60) = 15.617$, $p < .001$); infants looked longer at 2-object displays (M = 9.8s) than 1-object displays (M = 7.5s). There were no interactions among these variables. For our purpose, it was especially important that there was no three-way interaction ($F(1, 60) = .944$, $p = .335$). This shows that the pattern of results for the Different Condition was not statistically different from that of the Same Condition.

All babies in Experiment 3 were videotaped. Off-line observers, who were completely blind to which condition the baby was in or in which order the stimuli were presented, scored the videotapes. Interscorer reliability averaged 90%.

Discussion

Experiment 3 replicated and extended our findings from Experiment 2. In Expt. 3, we tried to break the illusion of an oscillating single trajectory by leaving the toys out for the baby to habituate to. That this manipulation did not change the results suggests that it was unlikely that in Expt. 2 the oscillating motion provided positive evidence for the babies that there was only one object. In Expt. 3, we have shown that the babies' failure is not due to not noticing the property differences between the two objects. Rather, the babies noticed the perceptual differences between each pair of objects, but they failed to use that information to infer that there were two objects behind the screen. Expt. 3 makes the important conceptual point that setting up representations of two numerically distinct individuals is different from noticing the property differences between two presentations of what might be one or two objects.

The data from Expt. 3 are consistent with the strong claim that the property differences between the two objects had no effect at all on the baby's looking time patterns, since there was no three way interaction between condition (Same vs. Different), trial type (baseline vs. test) and number of objects in the outcome (1 vs. 2). However, it is likely that the babies' looking preference for two objects in the test trials of the Same Condition had a different source from superficially the same preference in the test trials of the Different Condition. First, babies had habituated in the Same Condition, but not in the Different Condition (see Figure 5). Thus, while infants had noticed the property differences between the two objects, perhaps they had not fully encoded them, and that is why they had not concluded that there were two distinct objects. Perhaps they did expect two objects, but since they were in the midst of habituation, they had a preference for the expected outcome. Experiment 4 addresses these possibilities with a full habituation paradigm.

A second reason to suspect that the babies' preference for two objects in the Same Condition has a different source from that in the Different Condition is that in the Different Condition, the preference for two objects was the baseline preference and in the Same Condition it was not.[6] The significant preference for two objects in the test trials of the Same Condition is closely analogous to the

---

[6] Note, however, that there was no baseline by test interaction in either the Same or the Different Condition.

preference for two objects in the Continuous Condition of Experiment 1. In both cases, it may simply reflect familiarity with "oneness" and novelty with "twoness." (This factor could be playing a role in the preference for two objects in the Different Condition as well.) Alternatively, it is possible that the infants' analysis of the properties of the objects contributed to an expectation of one. However, the fact remains that the infant was not able to use the *differences* of properties in the Different Condition to establish representations of two distinct objects.

Experiment 4

The results so far still leave open the possibility that 10-month-olds can use property/kind information to trace identity, but they simply cannot do so as efficiently as they can use spatiotemporal information. First, we have not so far used a full habituation paradigm, so we have not given babies the greatest possible opportunity to set up representations of two objects in the property/kind condition. Second, recall that in Expt. 2, the infants in the spatiotemporal condition showed a significantly shorter looking time on the introductory as well as the test trials than did the infants in the property/kind condition. This fact may be important, since it raises the possibility that the success of the babies in the spatiotemporal condition was due to their being fast habituators. The lack of habituation in the Different Condition in Expt. 3 also points to the possibility that the infants might not have had sufficient time to set up representations of two distinct objects in the experiment. And finally, the relatively unfamiliar objects used in Expts. 2 & 3 might have contributed to their failure.

Experiment 4 compared two conditions, Property/kind and Spatiotemporal, in a full habituation procedure. Since babies were randomly assigned to these conditions, we expected no sampling differences between the two groups in Expt. 4. Experiment 4 introduces three changes to Experiment 2. First, new objects were used, ones judged to be highly familiar by parents (bottle, ball, cup, and book). Second, only one pair of objects was used in the test trials (due to full habituation). Third, the introductory trials used two pairs of dissimilar and distinct objects, therefore providing a within-subject baseline.

Method

Subjects

Twenty-four full-term infants participated in the study (11 girls and 13 boys). Half of the infants were randomly assigned to the property/kind condition; their mean age was 10 months 6 days (ranged from 9 months, 20 days to 10 months, 20 days). Half of the infants were randomly assigned to the spatiotemporal condition; their mean age was 10 months 1 day (ranged from 9 months 16 days to 10 months 13 days). All infants were recruited from the Greater Boston area as in previous experiments. One additional infant was eliminated from the study due to fussiness.

Materials and Apparatus

Six toys were used as stimuli: a red metal toy truck, a gold wire basket, a tennis ball with green and pink stripes, a bottle with small light blue bear pattern, a sippy cup with a red top, and a yellow baby book. The apparatus was the same as in Expt. 3. All sessions were videotaped for off-line observing; the videotapes provided no information about what was shown on the stage or in what order objects were shown.

Design and Procedure

Before the experiment, parents were asked to fill out a questionnaire to indicate whether their infants were familiar with the objects in the stimulus set (ball, bottle, cup, and book) on a 1 to 5 rating scale and whether they thought their infants understood the words for these objects (yes or no).

Baseline/Introductory Trials. Expt. 4 used a within subject baseline. In order to maximize the reliability of the baseline as an accurate measure of the infants' intrinsic preference, the following design was adopted: for half of the infants who had bottle and ball as their test stimuli, the other two pairs of objects, namely truck and basket, and cup and book, were used as baseline stimuli; for the other half of the infants who had cup and book as their test stimuli, truck and basket, and bottle and ball were used in the baseline. The baseline/introductory trials were carried out exactly the same way as in previous experiments with order of objects and order of outcome (1, 2, 2, 1 or 2, 1, 1, 2) counterbalanced across subjects.

Property/Kind Condition. After the four baseline/introductory trials, habituation began. The experimenter lowered a screen with two objects concealed behind it. To minimize the difference between this condition and the spatiotemporal condition (see below), she first showed the infant objects briefly one at a time: one object was brought out to one end of the stage, tapped for 3 or 4 times, the infant's attention was drawn to it, "Look, [baby's name]", and returned behind the screen. The second object was then brought out briefly to the other end of the stage in the same manner. Then the habituation phase began. The experimenter brought out the first object, say a bottle, to one end of the stage, tapped the object on the stage 3 or 4 times while saying "Look at this, [baby's name]", then left the object there for the infant to look at until the infant turned away for two consecutive seconds. The experimenter then brought the first object back behind the screen. After a brief pause, she brought out the second object, say a ball, to the other end of the stage. She tapped the object on stage, drew the infant's attention, and left it in full view for the infant to look at until the infant turned away. This sequence was repeated until either the habituation criterion was met, i.e. the average looking time for the last three trials was half of the average for the first three trials, or when the baby had looked for 14 trials. To remind the baby that there were two objects behind the screen, objects were then brought out briefly one at a time without being left stationery for the infants to look at. After habituation and the two brief emergences of the objects, the experimenter removed the screen to the side revealing one or two objects. After the baby looked away, the stage was cleared. A different color screen was then lowered with the same two objects concealed behind it. The experimenter showed the infant each object briefly one at a time then removed the screen to the side to reveal the objects. This sequence was repeated until 6 test trials were completed. The test trials were in the order of 1, 2, 1, 2, 1, 2 or 2, 1, 2, 1, 2, 1, counterbalanced across subjects.

Spatiotemporal Condition. As in the Property/Kind condition, habituation began after the four baseline/introductory trials. The experimenter lowered a screen with two objects concealed behind it. She brought out the first object, say a bottle, to one end of the stage, tapped it on the stage for 3 or 4 times, and drew the baby's attention to it "Look, [baby's name]"; she then brought out the second object, say a ball, to the other end of the stage when the first object was in full view, tapped the second object for 3 or 4 times, and drew the baby's attention to it "Look, [baby's name]. The experimenter then tapped both objects on the stage simultaneously for 3 or 4 times while saying "Look, [baby's name]" and brought them behind the screen together. The timing of this event was matched with the timing of the Property/Kind condition's brief emergences of the two objects. Then the habituation phase began; it was carried out in exactly the same way as in the Property/Kind condition, i.e., each infant looked at the two objects alternately (not simultaneously) until s/he met the habituation criterion. When the baby reached habituation criterion or looked for 14 trials, the two objects were again brought out for a brief period simultaneously and returned behind the screen. The experimenter then removed the screen to the side revealing either one or two objects. After the baby looked away, the stage was cleared. A different screen was then lowered with the same two objects concealed behind it. The experimenter showed the two objects simultaneously for a brief few seconds, returned them behind the screen, then removed the screen to the side to reveal the objects. This sequence was repeated until 6 test trials were completed. The test trials were in the same orders as in the Property/Kind Condition, counterbalanced across subjects.

Results

Twenty-two of the 24 infants' parents filled out the questionnaires. Parental reports indicated that the objects we used in the study were indeed very familiar to the infants of this age. With 1 being very familiar and 5 being very unfamiliar, the mean ratings for the objects were as follows: ball - 1.5, bottle - 1.9, book - 1.5, and cup - 1.4. In addition, babies were judged to understand the words that label these objects more than half of the time. The rates of parentally judged comprehension were comparable to those gathered on the MacArthur

Communicative Development Inventory (Fenson, et al. 1991): ball - 59.1% (MacArthur, 59.7%), bottle - 63.6% (MacArthur, 68.7%), book - 63.6% (MacArthur, 50.7%), and cup - 54.5% (MacArthur, 41.8%). Since parents were instructed to give us their best guess as to whether the child understood the words, we don't know how reliable these figures are.

The mean numbers of trials taken to reach habituation criterion were 9.3 trials for the property/kind condition and 10.3 trials for the spatiotemporal condition. A t-test revealed that they did not differ from each other ($t(22) = .887$, $p = .39$).

The main findings of Expt. 4 are shown in Figure 7. Baseline/introductory trials, which were identical in both conditions, were examined for effects of condition (property/kind vs. spatiotemporal) and number (1 vs. 2). An ANOVA revealed a main effect of number, $F(1,22) = 4.904$, $p < .04$, and no interaction between the two variables. The main effect for number reflects the baseline preference for displays of two objects, also seen in the baseline trials of Expts. 2 & 3. There was a fairly strong preference for looking longer at two-object displays in both conditions (Property/Kind condition: Mone-obj. = 6.8 s, SD = 2.5; Mtwo-obj. = 8.9 s, SD = 5.7; Spatiotemporal condition: Mone-obj. = 7.2 s, SD = 2.3; Mtwo-obj. = 9.7 s, SD = 6.6). As expected, there was no main effect of condition; the sampling difference between the two conditions of Expt. 2 was not found here.

Insert Figure 7 about here.

Separate ANOVAs compared baseline and test trials within each condition. The ANOVA examining the effects of trial type (baseline vs. test) and outcome (1 vs. 2 objects) on looking times in the property/kind condition revealed no main effects or interactions (Prop/Kind: Mone-obj. = 5.6s, SD = 1.6; Mtwo-obj. = 7.0s, SD = 2.8). The ANOVA examining the effects of trial type (baseline vs. test) and outcome (1 vs. 2 objects) in the spatiotemporal condition revealed an interaction between these two variables ($F(1,11) = 6.091$, $p < .04$; Mone-obj. = 7.7s, SD = 4.4; Mtwo-obj. = 7.0s, SD = 3.7). Finally, an ANOVA with condition (property/kind vs. spatiotemporal) and number of objects in outcome (1 vs. 2) revealed an interaction between the two variables ($F(1,22) = 4.324$, $p < .05$).

Nonparametric tests corroborated on the above results. In the property/kind condition, 8 out of 12 babies looked longer at 2-object displays on the baseline trials and 9 babies showed the same preference on the test trials; in the spatiotemporal condition, 8 out of 12 babies looked longer at 2-object displays on the baseline trials whereas only 4 babies showed the same preference on the test trials. A chi-square test revealed that the patterns on the test trials of the two conditions were different, c2(1) = 4.17, $p < .05$.

All infants in this study were videotaped and scored off-line by an observer. The average interscorer reliability was 91%.

We will defer discussion of the possible relations between word comprehension and performance on the task until after presenting Expt. 5.

Discussion

Despite all the changes between Expts. 2 and 4 -- new highly familiar objects, full habituation procedure -- Experiment 4 provides a complete replication of the results of Expt. 2. The full habituation paradigm gives the infant massive exposure to the objects, yet those in the property/kind condition still failed to overcome their baseline preference for two object displays. And again, those in the spatiotemporal condition succeeded in overcoming their baseline preference for outcomes of two objects.

In Experiment 4, the babies in the spatiotemporal condition did not differ from those in the property/kind condition in overall looking time, suggesting that the different pattern of results between the two conditions in Expt. 2 was not due to the sampling difference between the two groups. Rather, these data support the conclusion that the difference between the groups in Expts. 2 & 4 is due to the fact that 10-month-olds use spatiotemporal information to individuate objects but fail to use property/kind information to do so, at least under the circumstances of our experimental manipulations.

The data from Expt. 4 provide further evidence that setting up a representation of the properties of objects is psychologically separable from establishing representations of distinct individuals. Babies in the spatiotemporal condition established representations of two different individuals; babies in the property/kind condition did not. Yet both groups habituated to the familiarization emergences at exactly the same rate.

Together, Expts. 1-4 provide support for the *Object*-first hypothesis. These studies raise the question of when babies come to represent sortals more specific than *object*, such as *ball*, *bottle*, *book*, and *cup*.

Experiment 5

Experiment 5 addressed the question of at what age infants will use property/kind information to individuate objects under these conditions. In a pilot study, we tested a group of 11-month-olds under exactly the same conditions as the 10-month-olds of Expt. 2. Their preference for two-object outcomes was less than that of the 10-month-olds, but not significantly so. Therefore, we decided to test a group of 12-month-olds with the more familiar objects of Expt. 4. A new group of 10-month-olds were tested under the exact same conditions to provide a comparison and to provide still further possibility of disconfirmation of our basic findings in Expts. 2-4.

Method

Subjects

Thirty-two full-term infants participated in the study, including 16 10-month-olds (9 boys and 7 girls) with a mean age of 10 months, 1 day (ranged from 9 months 17 days to 10 months, 20 days) and 16 12-month-olds (10 boys and 6 girls) with a mean age of 12 months, 10 days (ranged from 11 months, 29 days to 12 months, 23 days). The infants were recruited from the Greater Boston area as in previous experiments. An additional four 10-month-olds were eliminated from the experiment due to fussiness; an additional three 12-month-olds were eliminated from the experiment due to fussiness (2) or experimenter error (1).

Materials and Apparatus

Two pairs of toys were used in baseline/introductory trials: a bunny and a basket; a toy truck and a camel. The same two sets of toys from Expt. 4 were used as stimuli for the test trials: ball, bottle, cup, and book. The stage was the same as in previous experiments. A video camera recorded the sessions for off-line observing; the videotapes provide no information about what was presented on the stage.

Design and Procedure

Before the experiment, parents were asked to fill out a questionnaire to indicate whether their infants were familiar with the objects in the stimulus set (ball, bottle, cup, and book) on a 1 to 5 rating scale and whether they thought their infants understood the words for these objects (yes or no).

The procedure was exactly the same as in the property/kind condition of Experiment 2 with both groups of infants. The only modification was that this experiment used a within-subject baseline; two pairs of objects were used during four baseline/introductory trials which preceded the test trials. Two orders of outcome on these baseline/introductory trials were 1,2,2,1 or 2,1,1,2. The order of objects and which object was in the single-object outcome were counterbalanced across subjects.

Results

Parental reports collected before the experiment showed that both groups of infants were very familiar with the stimuli. For each group, 13 of the 16 parents filled out the questionnaire. With 1 being very familiar and 5 being not familiar at all, the mean ratings for 10-month-olds were ball-2, bottle-1.7, cup-1.4, and book-1.7; the mean ratings for 12-month-olds were ball-1.2, bottle-1.6, cup-1.2, book-1.4. The ratings between the two age groups are not substantially different. For word comprehension, the proportion of infants who were reported to understand these words were: 10-month-olds: ball - 7.7% (MacArthur: 59.7%), bottle - 30.8% (MacArthur: 68.7%), book - 15.4% (MacArthur: 50.7%), cup - 7.7%

(MacArthur: 41.8%); 12-month-olds: ball - 84.6% (MacArthur: 79.5%), bottle - 84.6% (MacArthur: 77.3%), book - 53.8% (MacArthur: 68.2%), cup - 46.2% (MacArthur: 55.7%). As can be seen, the 10-month-olds in this study were rated as less likely to comprehend these words than were those in Expt. 4 and the MacArthur norms. The 12-month-olds were rated more likely to know these words than the 10-month-olds, and more or less in line with the MacArthur inventory norms.

The main results of the experiment, comparing 10- and 12-month-olds, are shown in Figure 8.

First consider the baseline/introductory trials. An ANOVA examined the baseline trials for both groups with age (10- vs. 12-month-olds) and number (1 vs. 2) as variables. There was no effect of age, a significant effect of number ($F(1,30) = 16.599$, $p < .0001$), and no interaction between these two variables. Infants looked longer at two-object displays (M = 10.3s) than one-object displays (M = 7.3s). Twelve of the sixteen 10-month-olds showed longer looking at two-object displays and 12 of the sixteen 12-month-olds showed the same preference. In sum, both age groups had an equally strong intrinsic preference for looking at two-object displays in the baseline/introductory trials.

Looking times for each group were analyzed in an ANOVA with trial type (baseline vs. test) and outcome (1 vs. 2) as within-subject variables. For the 10-month-olds, there was no main effect of trial type but there was a significant main effect of number ($F(1,15) = 10.692$, $p = .005$). Babies looked longer at 2-object displays (M = 9.8s) than 1-object displays (M = 6.7s). There was no interaction between trial type and outcome ($F(1,15) = .718$, $p = .410$; Baseline: Mone-obj. = 6.6s, SD = 3.1; Mtwo-obj. = 9.1s, SD = 3.7; Test: Mone-obj. = 6.9s, SD

= 2.8; Mtwo-obj. = 10.7s, SD = 5.6). Recall that there were two pairs of test trials, and the same pattern held for both of them (Trial pair 1: Mone-obj. = 7.1s, Mtwo-obj. = 10.7s; Trial pair 2: Mone-obj. = 6.7s, Mtwo-obj. = 10.5s). For the 12-month-olds, there was no main effect of trial type and a marginally significant effect of number (F(1,15) = 3.96, p = .065). Again, babies looked longer at 2-object displays (M = 9.6s) than 1-object displays (M = 8.4s). More importantly, there was a significant interaction between trial type and outcome (F(1,15) = 4.824, p < .05; Baseline: Mone-obj. = 8.1s, SD = 4.0; Mtwo-obj. = 11.5s, SD = 5.5; Test: Mone-obj. = 8.7s, SD = 3.7; Mtwo-obj. = 7.7s, SD = 3.8). Again, there were two pairs of test trials and the trial pair data were as follows: Trial pair 1: Mone-obj. = 8.2s, Mtwo-obj. = 8.5s; Trial pair 2: Mone-obj. = 9.2s, Mtwo-obj. = 7.1s.

An ANOVA analyzing the test trials only with age group as a between subject variable and outcome (1 vs. 2) as a within-subject variable showed no main effect of either age or outcome. Most importantly, there was an interaction between age group (10- vs. 12-months) and outcome (1 vs. 2), F(1,30) = 6.275, p < .02. This interaction confirms that the two groups of infants differed in their capacity to use property/kind information to establish representations of two distinct objects.

Insert Figure 8 about here.

Nonparametric tests confirmed the above results. For the 10-month-olds, 12 of the 16 infants looked longer at the two-object displays on the baseline trials and 13 of them showed the same preference on the test trials. In contrast, 12 of the 16 12-month-olds looked longer at two-object displays during baseline trials whereas only 4 12-month-olds showed the same preference on the test trials (Wilcoxin T = 29, $p < .05$, one-tailed). A chi-square test showed that difference between the two age groups on the test trials was significant, c2(1) = 8.03, $p < .01$.

Twelve of the 16 10-month-olds and 13 of the 16 12-month-olds were videotaped and observed off-line by observers who were blind to the order of the outcomes. The mean interscorer reliability was 94% and 91%, respectively.

Discussion

The 10-month-olds in Expt. 5 showed the same failure as those in Expts. 2-4. By 12 months of age, infants succeed at the task quite robustly. By this age, they are able to overcome a strong baseline preference for two-object displays, showing a very different pattern of looking on the test trials than on the baseline trials.

These data are consistent with the possibility that by 12 months of age, babies have constructed at least some sortals more specific than *object* (namely, *ball, book, cup,* and *bottle*). That is, babies can use membership in two of these kinds to individuate objects. However, these data do not allow us to decide whether 12-month-olds are using *property* information (e.g., the distinction between a bottle shape and a ball shape) or *kind* information (e.g., the distinction between a bottle and a ball) in individuating these entities.

In sum, these data are consistent with the hypothesis that 10-month-old infants have not constructed sortals corresponding to the kinds of objects used in these studies, even for highly familiar objects such as bottles and cups. By 12 months of age, babies may have done so.

Exploratory analyses of the noun comprehension data

There is a change between 10- and 12-month-olds' ability to use property/kind information to individuate objects, at least under the conditions of this study. The age at which this transition is made is significant, for these are the ages during which babies begin to comprehend words (Huttenlocher, 1974; Oviatt, 1980). Collapsing over Expts. 4 & 5, we have parental reports on infants' comprehension of the nouns for the four highly familiar objects in the test trials for twenty-three 10-month-olds and thirteen 12-month-olds.

Table 2 shows the distribution of number of words known by the infants. A Chi-square test shows that the distributions are different ($c2(4) = 10.2$, $p < .05$). Over half of the 10-month-olds were judged by their parents to know none or at most one of the four words. In contrast, the majority (85%) of the 12-month-olds were reported to understand two or more of the words, and most of them were credited with knowledge of 3 or 4 words. No 10-month-olds were judged to comprehend all 4 words whereas two of the 12-month-olds were. No 12-month-olds were reported to understand 0 words whereas nine 10-month-olds were. The correspondence in time of the two developments -- the ability to use the differences between a ball and a bottle to individuate objects and the ability to comprehend nouns such as 'ball' and 'bottle' -- raises the question of the relation between the two achievements. As a preliminary exploration of this relation, we analyzed 10-month-olds' performance on our object individuation task as a function of the number of words comprehended (see Table 3). Although there was not enough data to draw any strong conclusions, a very consistent pattern emerged. In both studies, the babies who knew 0 or 1 word failed at the task, exhibiting the baseline preference for two objects on the test trials. In both studies, the 10-month-olds who understood 2 or more words were able to overcome their baseline preference on the test trials and look about equally at the two outcomes. Note this latter pattern also characterizes the performance of the 12-month-olds.

In order to get enough data to do statistical analyses, we pooled the data from Expts. 4 and 5. An ANOVA examined the effect of comprehension group (0 or 1 vs. 2 or 3 words) and number of objects in the outcome (1 vs. 2) on looking times in the test trials. There was a main effect of number ($F(1,21) = 14.564$, $p < .001$). As always, the infants looked longer at 2-object outcomes. There was also a main effect of group ($F(1,21) = 4.683$, $p < .05$). The infants who knew fewer words looked longer ($M = 8.1$s) than the ones who knew more words ($M = 6.0$s). Most importantly, the interaction between these two variables was significant ($F(1,21) = 10.254$, $p < .004$). Those babies who understood more words overcame the baseline preference for two objects, performing like 12-month-olds or like 10-month-olds who have been provided spatiotemporal information. In sum, the number of nouns comprehended by 10-month-olds predicts their success at individuating objects under the condition of Expts. 4 & 5.

These studies were not designed to test the relationship between using property/kind information to individuate objects and noun comprehension, so we must emphasize the preliminary status of these findings. Still, the association appears strong in these data. Of course we cannot draw any conclusions about possible causal relations between the two abilities. It may be the case that word learning plays a role in establishing sortal concepts; it may be the case that infants do not begin to comprehend words for objects until they have constructed object kind sortals. However, given that these object words are among the first that infants acquire as established by the MacArthur Communicative Inventory

(Fenson, et al., 1991), the data are suggestive: the very first object words that infants acquire refer to object kind sortals.

General Discussion

The major result of these studies is the consistent failure of 10-month-old infants to use property/kind information to establish representations of two numerically distinct objects. The conditions under which they failed were quite varied -- full habituation to the two objects shown alternately (Expt. 4), partial habituation to the two objects (Expt. 3), and brief familiarization to the two objects (Expts. 2 & 5). Ten-month-olds failed with relatively unfamiliar objects (e.g., trucks, elephants; Expts. 2 & 3) and highly familiar objects (e.g., bottles, cups; Expts. 4 & 5).

The failures in Experiments 2-5 are consistent with the claim that 10-month-olds are unable to use property/kind information to support object individuation and numerical identity. However, two considerations mandate caution in reaching this conclusion. First, the strong baseline preference for two object outcomes in Experiments 2-5 raises the possibility that perhaps babies of this age *do* use property/kind information in object individuation, but cannot demonstrate this ability in these experiments. Of course, it is possible that some more sensitive method could be brought to bear on this question, but we are doubtful that the picture presented by these data will be radically revised. This is because our method was sensitive to variables that might, on theoretical grounds, be expected to influence performance. Most importantly, 10-month-old infants, when given spatiotemporal information, succeeded in overcoming the baseline preference for two objects (Expts. 2 and 4) and 12-month-olds succeeded in doing so given only property/kind information (Experiment 5). And most telling, in Experiments 4 & 5, 10-month-old infants whose parents judged them to understand the nouns for the familiar objects used as stimuli also succeeded in overcoming the baseline preference for two objects. These *successes* show that the baseline preference does not totally swamp any indication that the babies are expecting two objects behind the screen. Thus, the failures of the 10-month-olds in the property/kind condition probably indicate that they had not established representations of two objects in these events.

Indeed, our method is more sensitive than others that have been brought to bear on the question. LeCompte & Gratch (1972) assessed whether babies searched for the original toy when it had been mysteriously replaced by a second one after being hidden. Only at 18 months did babies do so, consistent with the conclusion that younger babies did not know that there were two objects involved in the event. Similarly, Gratch (1982) did not find babies looking back when one toy disappeared behind a screen and a different toy emerged until 16 months of age. Our data suggest that these earlier studies overestimated the age at which babies begin to use property/kind information to establish representations of numerically distinct objects.

The second reason we should be cautious in drawing conclusions from the results presented is that we only sampled a few cases of property/kind contrasts (yellow rubber duck/white foam ball; red metal truck/light blue elephant; bottle/ball; cup/book). However, there are at least three reasons to believe that these results would generalize beyond the particular pairs of objects probed here. First, the habituation data from Experiment 3 showed that infants *noticed the differences* within each pair of objects, so the failure cannot be due to our choice of property distinctions the baby is not sensitive to. Second, the objects used in Expts. 4 and 5 were extremely familiar to 10-month-old infants, so the failure cannot be explained by unfamiliarity with the stimuli. Third, the contrasts used in these studies span the global contrasts (animal/artifact; vehicle/animal) that Mandler and her colleagues (Mandler & Bauer, 1988; Mandler, Bauer, & McDonough, 1991) posit to be the first kind distinctions infants make. However, it is very much an open question whether other contrasts (e.g. extreme size differences; kind changes between a living, moving entity and an inanimate entity) would lead 10-month-old infants, or even younger infants, to infer that two distinct objects were involved in these events.

Thus, although these data are consistent with the *Object*-first hypothesis, they do not establish that it is true. Nonetheless, the finding that sortals such as *duck, truck, cup, bottle, ball,* and *book* do not provide criteria for individuation and identity for 10-month-olds has implications for the many habituation studies which have shown that even much younger infants are sensitive to such categories of objects. That is, much younger infants can habituate to a series of objects (e.g., stuffed animals) that they can discriminate, then dishabituate to an object from a different category (e.g., a cup; Cohen and Younger, 1983; Quinn and Eimas, 1993). Such results were obtained in both manual and visual habituation paradigms (Oakes, Madole, & Cohen, 1991). They are often interpreted as bearing on what kind concepts the infant represents (e.g., basic level kinds; cf. Macnamara, 1987; Roberts and Horowitz, 1986; global kinds, Mandler, Bauer, & McDonough, 1991). The present studies indicate that the categories revealed by these visual/manual habituation studies probably reflect perceptual distinctions that infants are sensitive to, not sortals or kinds that can support the learning of count nouns. Infants may be able to habituate to animal-shape, or animal-ness, without encoding these habituation exemplars as "an animal, another animal...". The studies reported here show that sensitivity to property differences between two entities is not tantamount to representing them as two distinct individuals. The fact that infants distinguish cups from balls in their action has no direct implications for how babies individuate entities with cup-like and ball-like properties. Similarly, even though infants react differently to their mothers and fathers, experiments such as the ones reported here would be required to establish when infants represent their mothers and fathers as distinct individuals. Indeed, Meltzoff & Moore (1992) presented some preliminary evidence suggesting that very young infants do not use properties to individuate people but rather rely on spatiotemporal information.

If infants are not representing the familiarization emergences in the property/kind conditions of Experiments 2-5 as involving two distinct objects, how might they be representing them? The results suggest that 10-month-old infants were agnostic about whether there were one or two objects behind the screen. In all four versions of the property/kind condition in Expts. 2-5, we found no statistical difference between the test trials and the baseline, as if the infants had not seen any of the emergences and when the screens were taken away, they simply exhibited their baseline preference for two objects. The baby seems to be representing the event as OBJECT emerging from the left of the screen, followed by OBJECT emerging from the right of the screen, and she represents these neither as a single object (OBJECTi) nor as distinct objects (OBJECTi, OBJECTj). Adults encounter such situations sometimes. Suppose you see a leaf on the sidewalk as you walk to class, and you see a leaf at roughly the same place on the sidewalk as you return from class. That may be the same leaf or it may not; your conceptual system is capable of drawing that distinction, but you leave the question open due to insufficient evidence.

An alternative interpretation of the results is that the infants may actually establish a representation of a single object (OBJECTi) moving back and forth behind the screen, attributing to this object the properties of being yellow and duck-shaped at times and white and ball-shaped at other times. If this were the case, the infants should have been surprised at two-object outcomes. The lack of difference between the test and the baseline trials may be due to the strong intrinsic preference for two objects masking the hypothesized surprise at two on the test trials. That is, the looking time measure may not be sensitive enough to reveal a surprise reaction on top of a strong intrinsic preference. This is, of course, speculative. The data at hand do not allow any conclusions to be drawn.

We do not know how exactly the infants may be representing the events. What is important is that both possibilities differ from adult representations of these events. Precisely because adults use property/kind information to establish numerically distinct objects, they are not agnostic when shown a toy duck at time 1 and a ball at time 2 emerging from behind the same screen. The adult's inference is clear and determinate: there are *two* objects in these events, a duck and a ball, and they will be surprised if shown only one object behind the screen.

By 12 months of age, infants succeed quite robustly in our task; that is, they succeed under conditions of four brief familiarization emergences of each object (Expt. 5). We have recently found convergent evidence of 12-month-olds' success (Xu, Carey, Raphaelidis, & Ginzbursky, 1994). Babies were trained to reach through a small hole on the top of a box to retrieve objects. Then they were shown objects being pulled out of the box one at a time, say, a toy duck being pulled out and put back in the box, then a ball being pulled out and put back in the box. The measure of how many objects they think are in the box is how many times they reach into it. We found that 12-month-olds reached roughly twice when shown two distinct objects and that they reach roughly once when shown a single object twice.

It is not the case that 10-month-old infants do not have any conceptual categories in the sense of sortal concepts. As demonstrated by Spelke & Kenstenbaum (1986) as well as Expts. 1, 2, & 4, in the present studies, infants as young as 4 months and 10 months represent at least one sortal concept, *physical object.* The criteria for individuation and identity for *physical objects* are spatiotemporal. Even though 10-month-old infants may not represent *ball, truck, duck, elephant , bottle, cup,* and *book* as kind, or sortal, concepts, the very existence of the sortal *physical object* shows that their conceptual system is capable of representing sortal concepts that provide conditions of individuation and identity. The concept *physical object* does more conceptual work for the infant than just this. A wealth of evidence gathered in the last ten years shows that infants' representations of objects are embedded in a system of intuitive physics that supports inferences about object motion and causal interactions (Leslie & Keeble, 1987; Spelke, 1988, 1992; Baillargeon, 1993, 1994).

What causes the changes observed in these studies between 10- and 12-month-olds? The fact that the change seems to be taking place during a rather short time window suggests that there may be maturational changes underlying the developmental accomplishment. It is also possible that the construction of specific sortals is the result of a learning process. We can imagine three different learning mechanisms.

The first draws on the *Object*-first hypothesis. Note that which properties of objects remain constant through time and which do not vary from object kind to object kind. For example, we expect the shape of a cup to remain constant over time, but are not surprised when the shape of a dog undergoes constrained transformations. The infant must learn which properties stay constant for various categories of objects. In order to learn this, however, the infant must have some way of individuating objects and tracing them through time. The spatiotemporal criteria for object fulfill this need. Perhaps the infant establishes individuals by spatiotemporal means, and learn how properties covary within individuals, and how some property clusters predict some property changes and other property clusters predict others. For example, babies may observe that a human hand traversing a spatiotemporally continuous path (evidence that it is one and the same hand) can change shape quite drastically therefore conclude that shape change is not a good indicator of change of identity in the case of a human hand. It is possible that kinds are then abstracted from this correlational analysis.

A second possibility grants the infants the concept of more specific kinds/sortals all along, in the absence of any examples. Perhaps also the infant knows innately that nouns refer to kinds (Pinker, 1984; Macnamara, 1987). If the infant picks out the referentially used words, and if the infant has learned through experience about what properties are likely to change for individual objects, the infant might then be in a position to use adult word usage as evidence for kind distinctions. This would predict the association between word comprehension and success on our tasks in Expts. 4 & 5. (Of course, as noted above, there are alternative interpretations of this association.) The limiting factor, in this scenario, comes from language learning -- at least the child must isolate some words before this form of evidence would be available.

A third possibility also grants the infant an antecedent notion of specific kind in the absence of any example. Infants may also expect kind distinctions to predict functional distinctions between objects. Baldwin, Markman, & Melartin (1993) showed that 9- to 16-month-olds were able to predict that if one horn honked, a perceptually similar horn would honk.[7] Perhaps learning the functions of objects helps the infant construct kinds because they may expect objects with the same function to be in the same kind and objects with different functions to be in distinct kinds.

These three sorts of input to a learning procedure (correlational analyses, referential word usage, functional analyses) are not mutually exclusive. All could play a role in the construction of sortals more specific than *object*.[8]

---

[7] Examining the data from their study suggests that this ability was fragile in the 9- to 10-month group. That is, in spite of the absence of significant age effects, it is clear that the 9- and 10-month-olds did not have as strong expectancies about the second toy, perhaps because they have not yet constructed the kind concepts (as specific sortals).

[8] The finding that babies use spatiotemporal information to individuate objects before they use property/kind information bears a formal similarity to findings in the apparent motion literature (Ternus, 1926/1938; Kahneman and Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992). If the temporal parameters are those that give rise to apparent motion, a display consisting of two objects (Xi and Xj), followed by a display containing two objects (X? and X?) in new locations, followed by the original, and so forth, will be perceived as two objects each moving back and forth between two locations. The question is which of the second objects (X? and X?) is seen as Xi in a second location and which as Xj? Spatiotemporal information, rather than property/kind information, is the determining factor. That is, subjects will see two cases of red squares turning into green circles rather than a red square moving back and forth and a green circle moving back and forth, if the former solution to establishing the individuals in the display minimizes the total amount of motion. At least in two cases then, spatiotemporal information dominates property/kind information in individuating entities and tracking identity over time: over very short term perceptual processing (as tapped by the apparent motion studies, where milliseconds make a difference) and over much longer conceptual processing in infants (as tapped by the present studies). Further studies will explore the relations between the two phenomena.

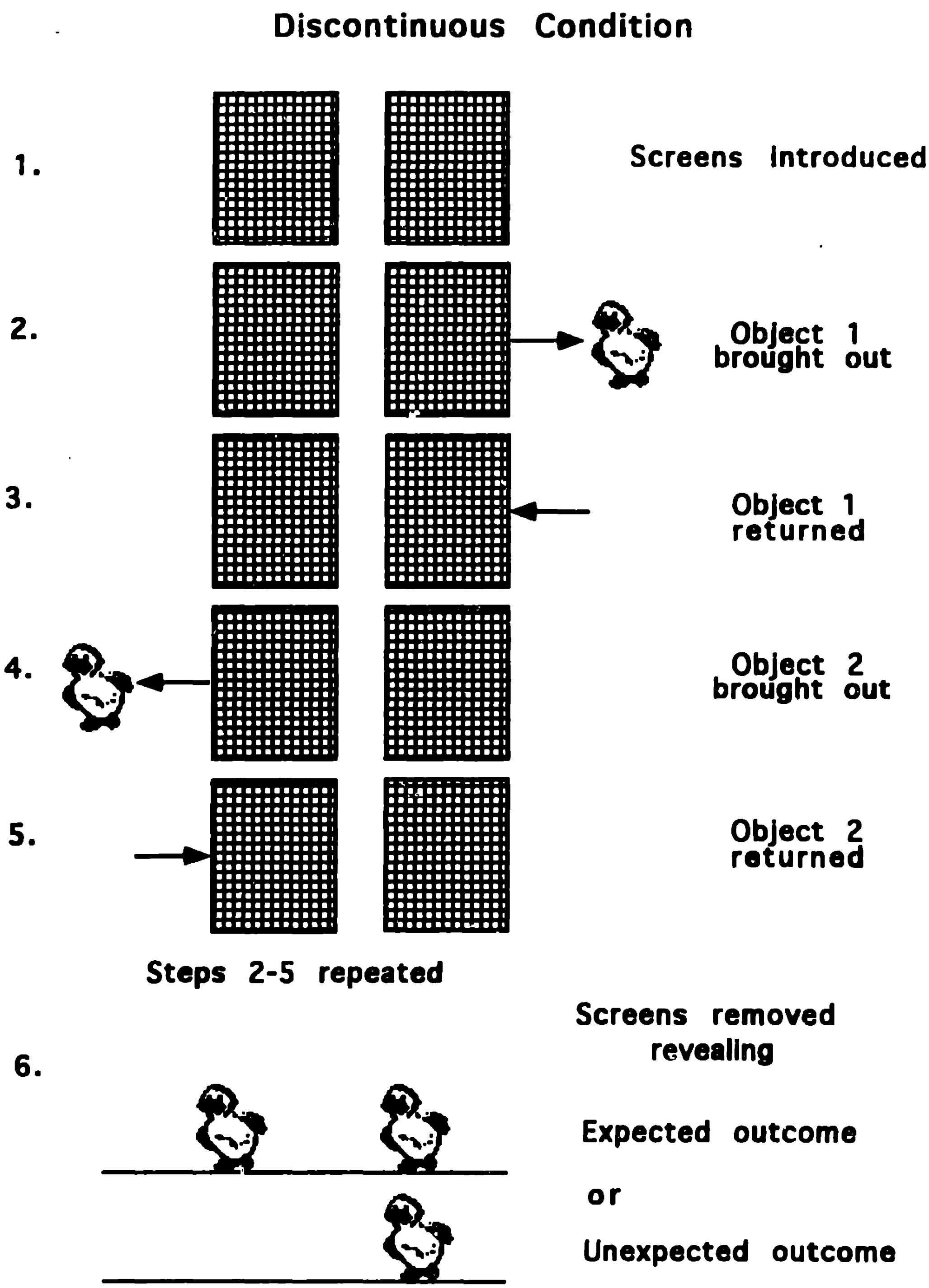

Discontinuous Condition
1.
Screens introduced
2.
Object 1 brought out
3.
Object 1 returned
4.
Object 2 brought out
5.
Object 2 returned
Steps 2-5 repeated
6.
Screens removed revealing
Expected outcome
or
Unexpected outcome

Figure 1

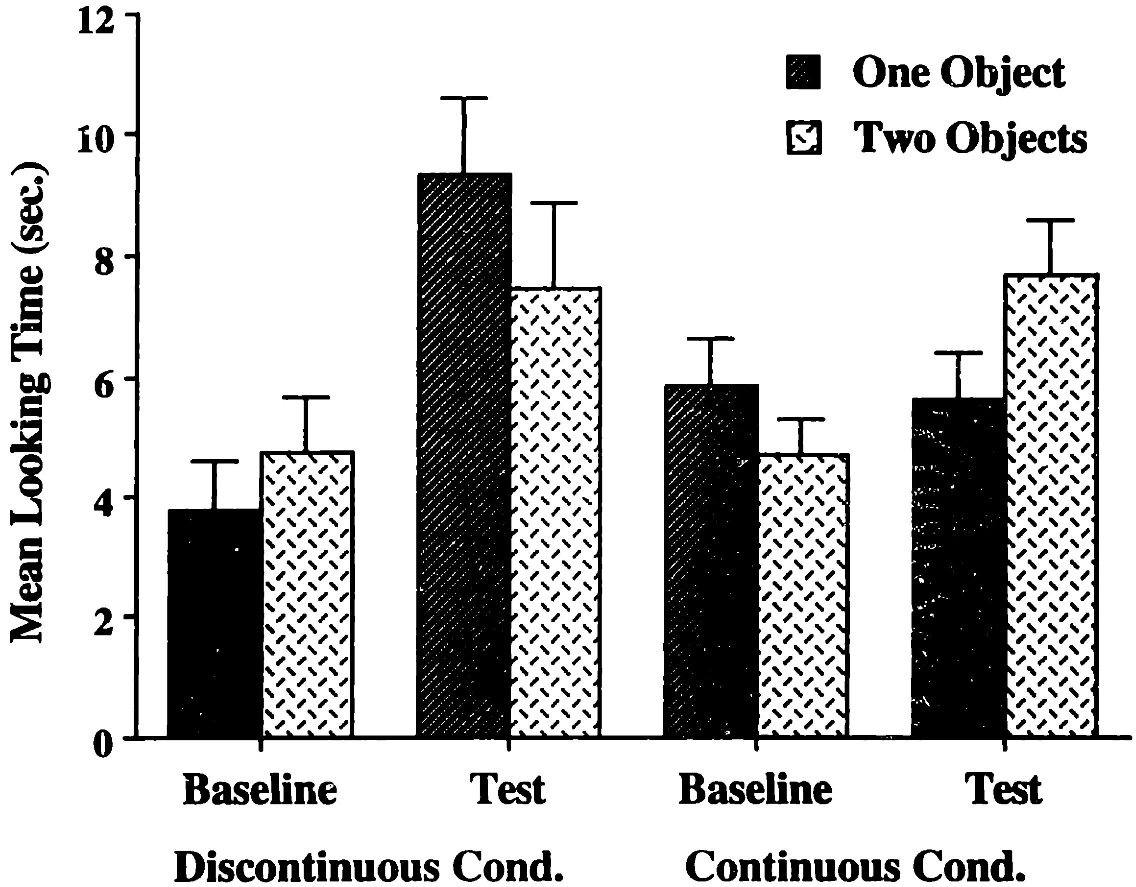
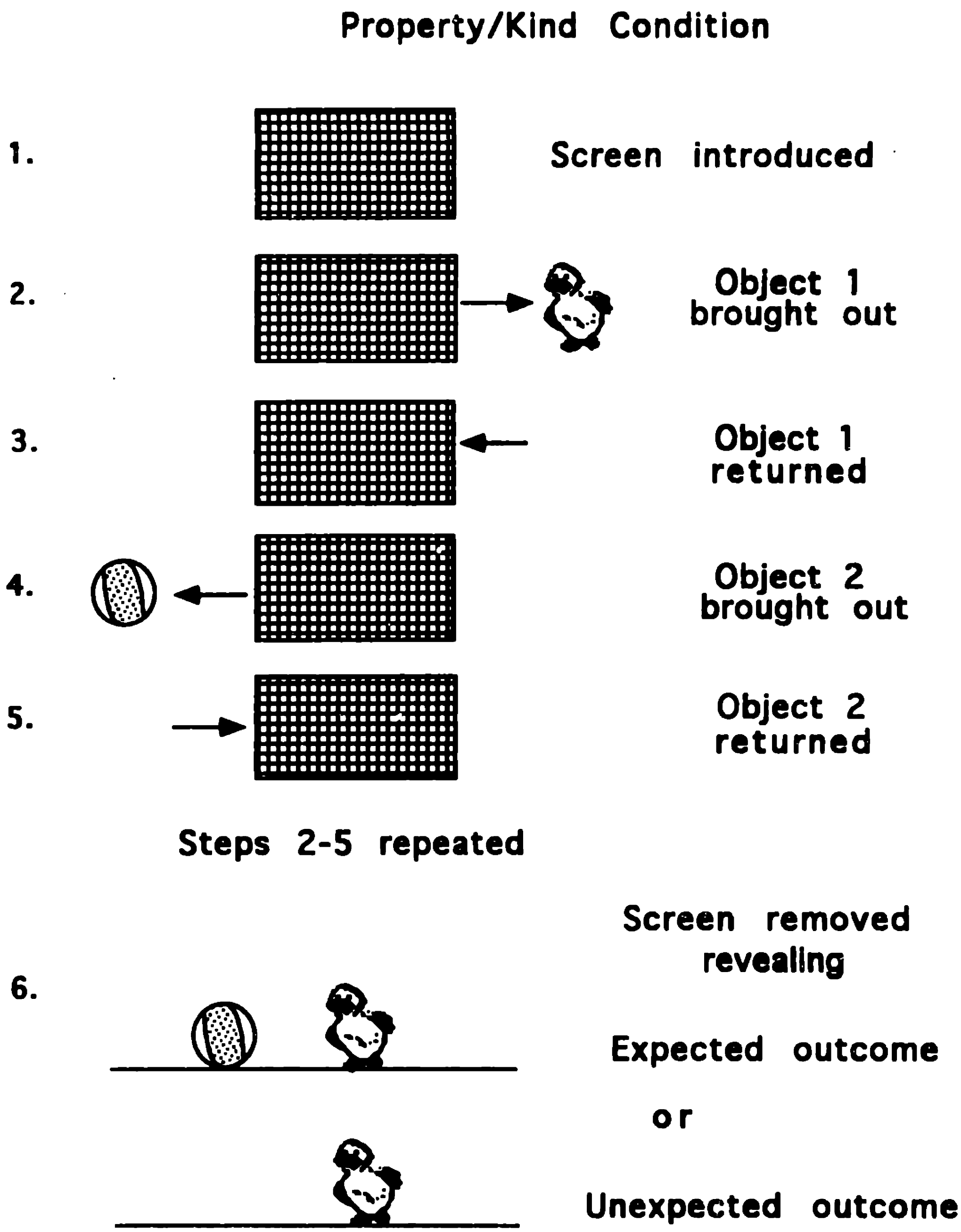

12
10
8
6
4
2
0
Mean Looking Time (sec.)
One Object
Two Objects
Baseline
Test
Baseline
Test
Discontinuous Cond.
Continuous Cond.

Figure 2



Property/Kind Condition
1.
Screen introduced
2.
Object 1 brought out
3.
Object 1 returned
4.
Object 2 brought out
5.
Object 2 returned
Steps 2-5 repeated
6.
Screen removed revealing
Expected outcome
or
Unexpected outcome

Figure 3.1

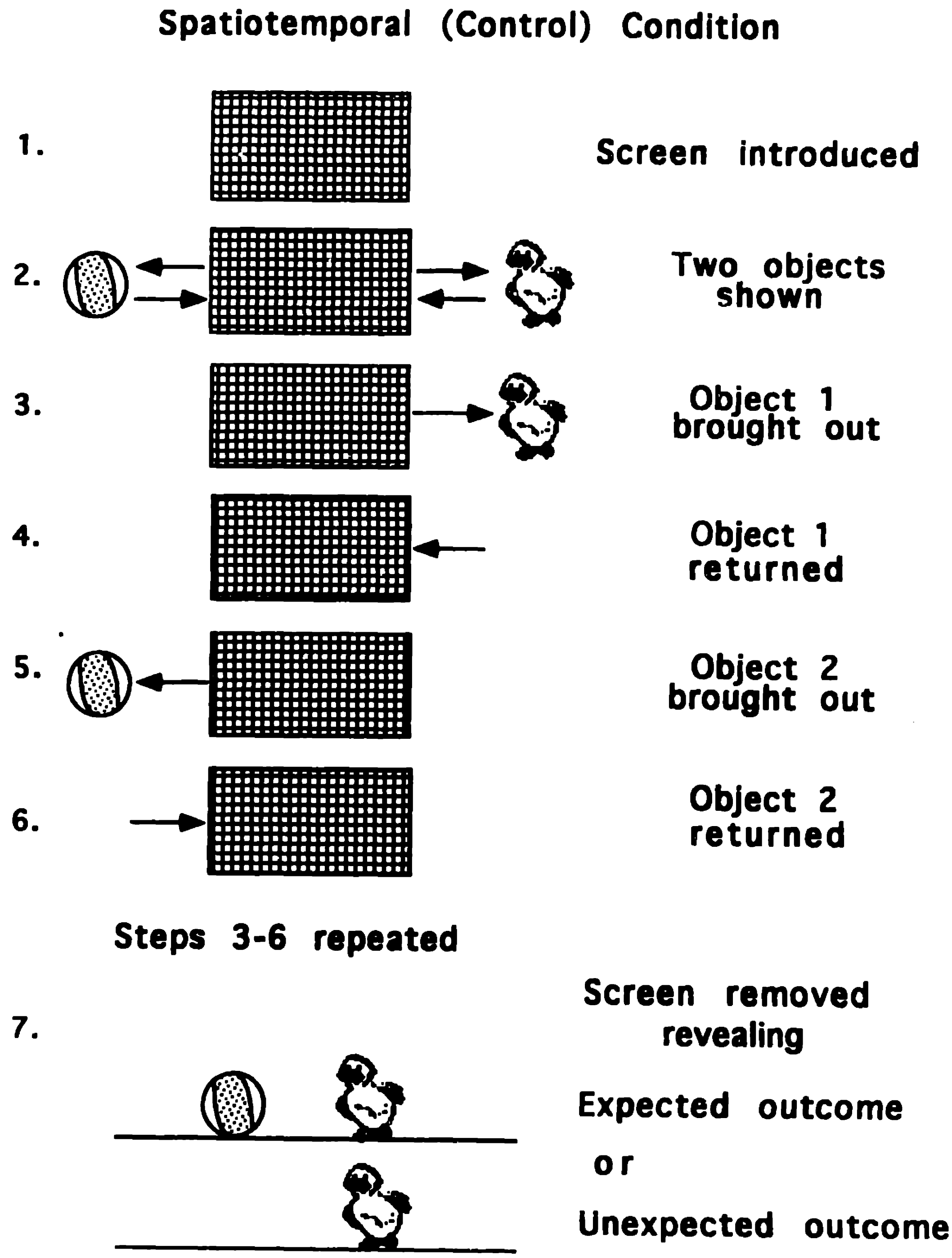

Spatiotemporal (Control) Condition
1.
Screen introduced
2.
Two objects shown
3.
Object 1 brought out
4.
Object 1 returned
5.
Object 2 brought out
6.
Object 2 returned
Steps 3-6 repeated
7.
Screen removed revealing
Expected outcome
or
Unexpected outcome

Figure 3.2

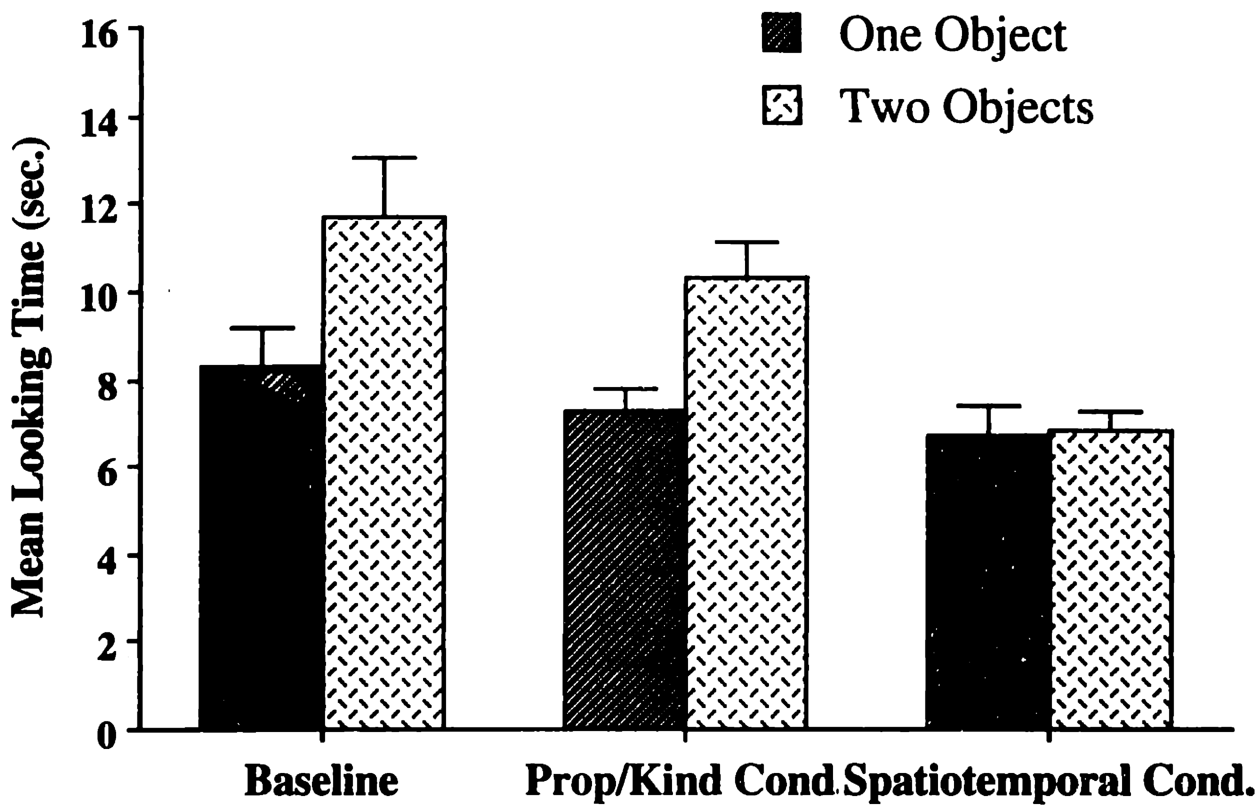

One Object
Two Objects
Mean Looking Time (sec.)
16
14
12
10
8
6
4
2
0
Baseline
Prop/Kind Cond.
Spatiotemporal Cond.

Figure 4

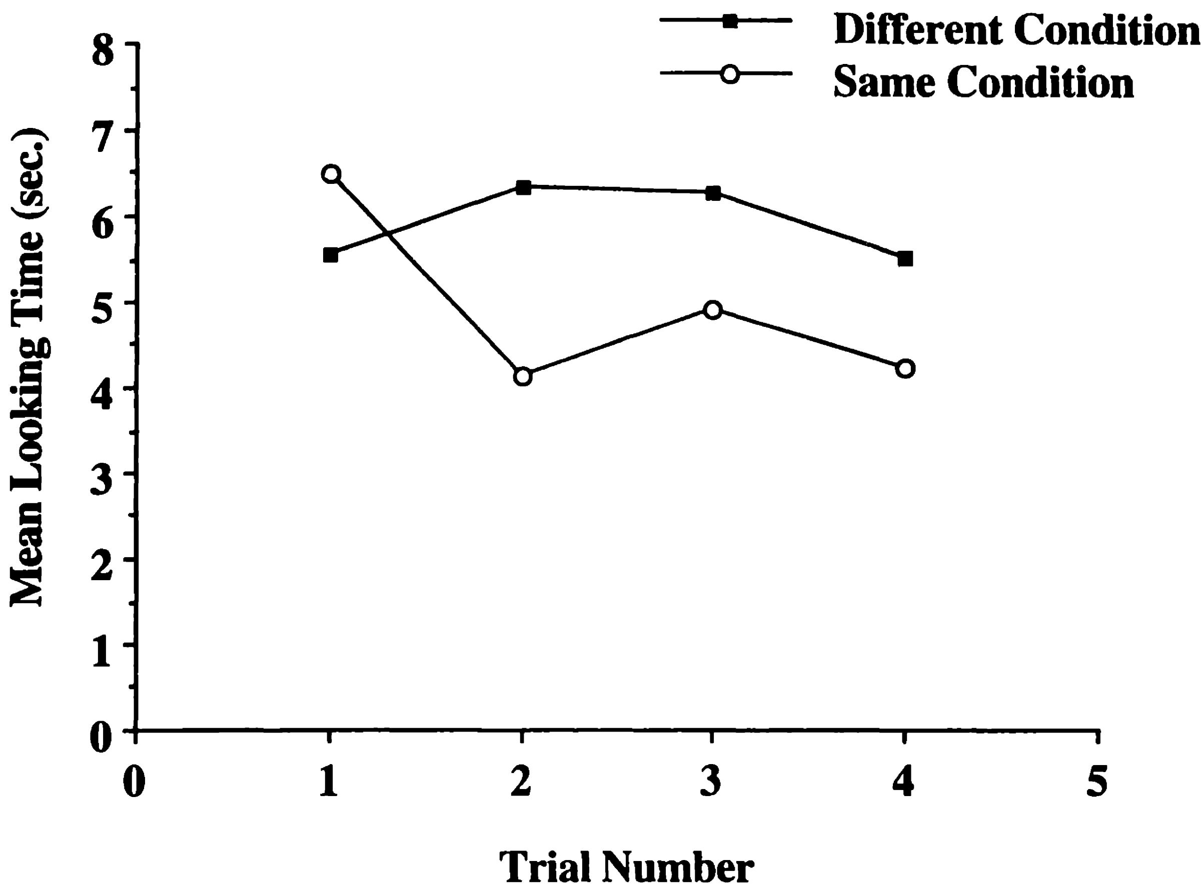

Different Condition
Same Condition
Mean Looking Time (sec.)
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
Trial Number

Figure 5

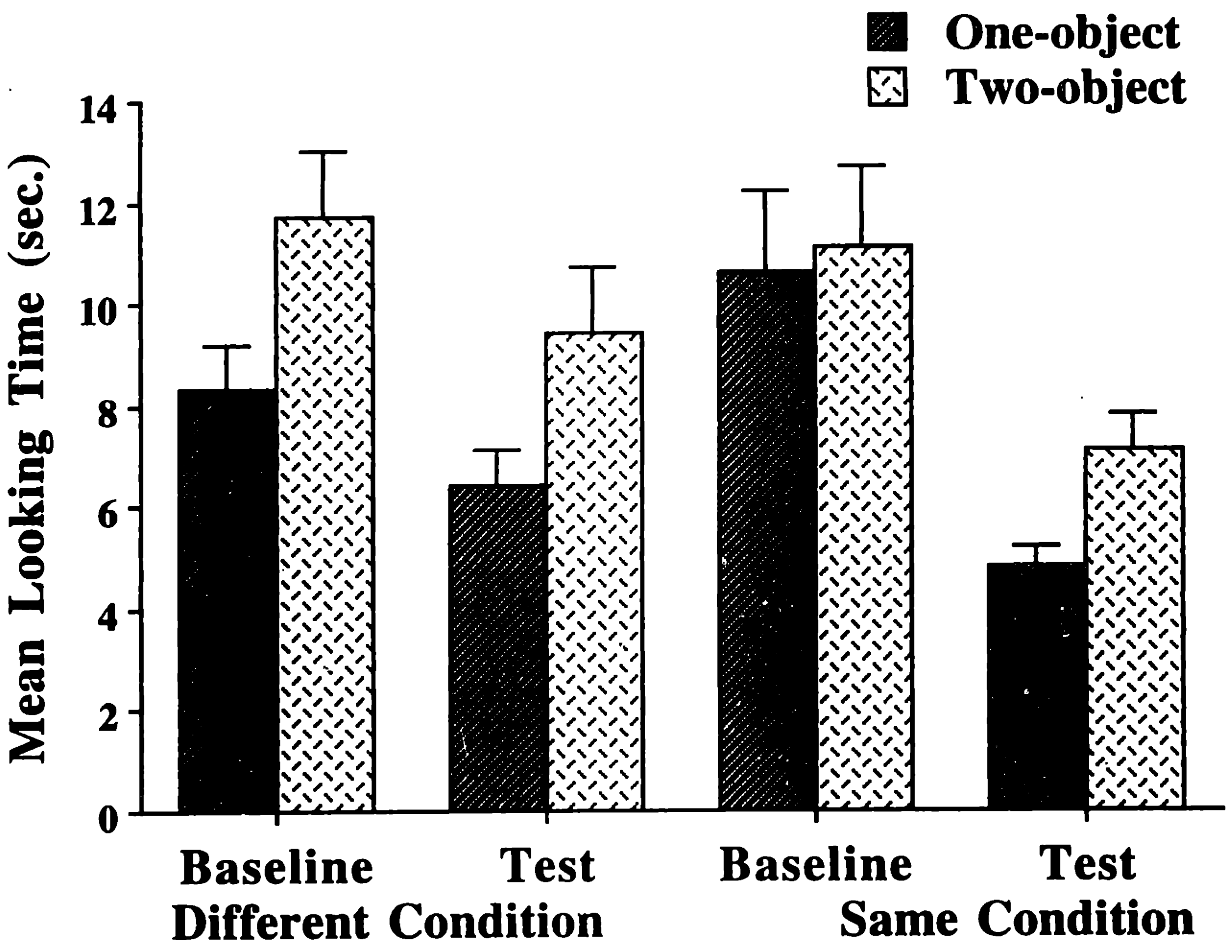

One-object
Two-object
Mean Looking Time (sec.)
14
12
10
8
6
4
2
0
Baseline
Test
Baseline
Test
Different Condition
Same Condition

Figure 6

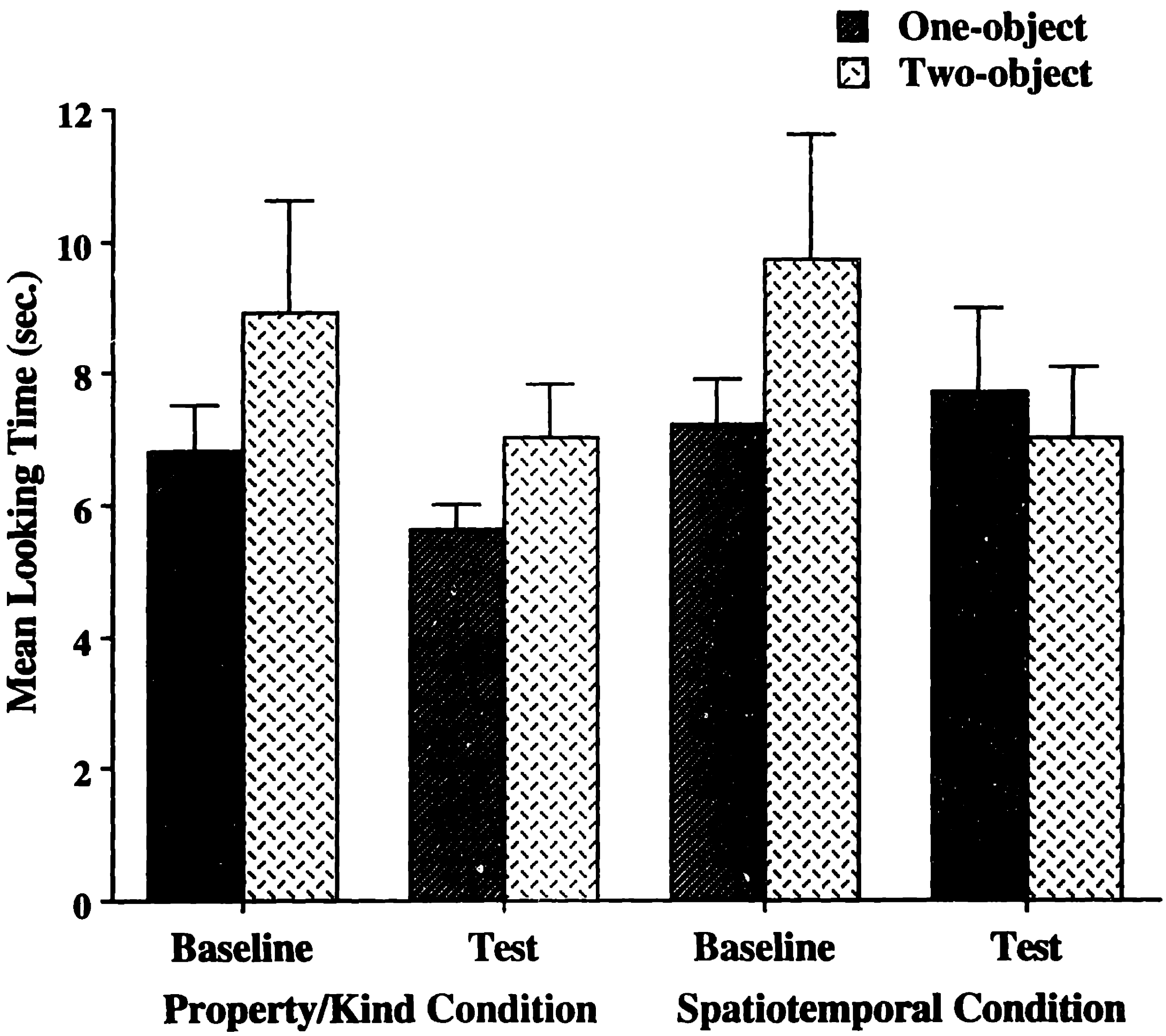

One-object
Two-object
12
10
8
6
4
2
0
Mean Looking Time (sec.)
Baseline
Test
Baseline
Test
Property/Kind Condition
Spatiotemporal Condition

Figure 7

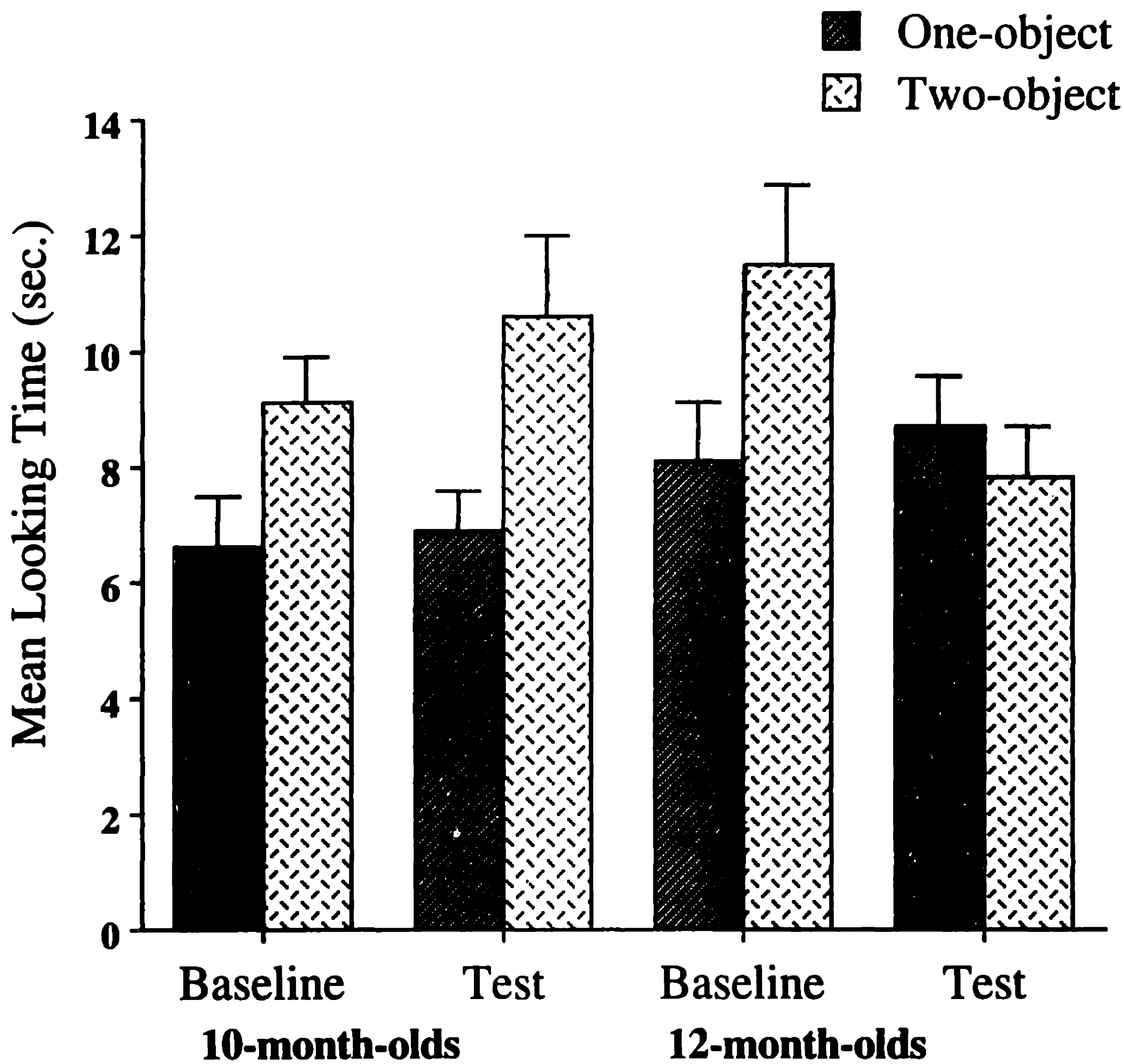

One-object
Two-object
Mean Looking Time (sec.)
14
12
10
8
6
4
2
0
Baseline
Test
Baseline
Test
10-month-olds
12-month-olds

Figure 8

Number of words understood	0	1	2	3	4
10-month-olds	9	4	6	4	0
12-month-olds	0	2	4	5	2

Table 1. Number of infants in each age group comprehending 0, 1, 2, 3, or 4 words

	Expt. 4		Expt. 5		Collapsing	Expts.4& 5
Comprehension Score	0 or 1	2 or 3	0 or 1	2 or 3	0 or 1	2 or 3
Number of subjects	n = 3	n = 7	n = 10	n = 3	n = 13	n = 10
2-object outcomes	8.2	5.5	10.3	7.2	10.1	6.0
1-object outcomes	5.1	5.6	6.7	6.9	6.3	6.0

Table 2. 10-month-olds' looking time patterns (in seconds) as a function of comprehension scores

Figure Captions

Figure 1. Schematic representation of the Discontinuous movement event and the expected and unexpected outcomes in Expt. 1.

Figure 2. Mean looking times of subjects in the discontinuous and continuous conditions to the baseline and test trials in Expt. 1.

Figure 3.1. Schematic representation of the Property/Kind condition: familiarization event and the expected and unexpected outcomes in Expt. 2.

Figure 3.2. Schematic representation of the Spatiotemporal condition: familiarization event and the expected and unexpected outcomes in Expt. 2.

Figure 4. Mean looking times in baseline, property/kind and spatiotemporal conditions of Expt.2.

Figure 5. Mean looking times for the habituation trials of Expt 3.

Figure 6. Mean looking times for the Different and Same conditions and their respective baseline in Expt. 3.

Figure 7. Mean looking times for property/kind and spatiotemporal conditions of Expt. 4.

Figure 8. Mean looking times for 10- and 12-month-olds in Expt. 5.

Chapter 3

Infants' Ability to Use Object Kind Information for Object Individuation*

Abstract

The present studies investigate the role of object kind information in infants' object individuation. Four experiments explored whether adults, 10- and 12-month-old infants could use their knowledge of toy ducks and toy cars to parse an array consisting of a duck perched on a car into two objects. In two studies using the visual-preference-for-novelty paradigm, 10-month-olds failed to do so, even after manipulating the duck and the car separately before being presented with the arrays. Infants of this age succeeded in using spatiotemporal information to parse the array into two objects; that is, they succeeded if shown that the duck moved independently relative to the car. By 12 months of age, infants succeed in using kind information in object individuation, as do adults. These findings shed light on the developmental course of object individuation and provide converging evidence for the *Object*-first hypothesis (Xu & Carey, in press): Early on, infants may represent one kind concept, *physical object*; more specific kind concepts such as *duck* or *car* may be acquired later in the first year of life.

---

* This research was supported by a grant from the NSF (BNS9012075) to Susan Carey. We would like to thank Gavin Huntley-Fenner, Gary Marcus, Cristina Sorrentino, and especially Elizabeth Spelke for comments on an earlier draft of the paper. We also thank S. Charles, A. Ginzbursky, C. Petrescu, K. Raphaelidis, & J. Tyan for their help in subject recruitment and data collection. Portions of this paper were presented at the 9th International Conference on Infant Studies and the 1995 Biennial Meeting of the Society for Research in Child Development.

Correspondence should be addressed to Fei Xu, E10-106, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, or E-mail to fei@psyche.mit.edu.

Perceiving the world in terms of distinct three-dimensional objects is one of our most fundamental cognitive capacities. The study of object perception divides into two enterprises: explaining object recognition (i.e., recognizing a given object as a member of the kind duck) and explaining object individuation (i.e., segregating a particular visual scene into distinct objects). In addition, the question of the relations between the processes underlying recognition and those underlying individuation also arises. For example, according to Marr (1982), prior to both individuation and recognition the visual system constructs a representation of continuous surfaces. He speculated that it is only after we recognize objects of particular kinds that we are able to parse the layout into individual objects. Similarly, there is a philosophical tradition which holds that it is in principle impossible to individuate objects without knowing what kinds the objects belong to (Geach, 1957; Gupta, 1980; Wiggins, 1967, 1980). Surely our knowledge of the kinds of things there are in the world helps us establish representations of the distinct objects in a visual scene; our knowledge of ducks and cars, for example, leads to a representation of two objects rather than one object when a toy duck sits on top of a toy car with no clear spatial boundary between them.

Although kind information is most definitely useful in object individuation, it is not always necessary. Two other classes of knowledge play a role: physical knowledge of how objects move and interact, and static configurational cues such as alignment of edges, textures, and regularity of shapes (e.g., Koffka, 1935). Furthermore, there is some evidence that infants can use the latter two sources of information well before they can exploit kind information in this process.

Three experimental paradigms, exploiting infants' tendency to look longer at unexpected than at expected events, have been developed to study infants' object individuation in visual arrays. First, Kellman & Spelke (1983) initiated this line of research with studies of the condition under which partially occluded stimuli were seen as a single connected object as opposed to two distinct objects. These studies show that patterns of relative motion of the visible parts of the stimulus, rather than static configurational cues, determine perception. Second, Spelke, Breinlinger, Jacobson, & Phillips (1993) investigated the condition under which a fully visible stimulus was expected to move as a whole or come apart when part of it was grasped and moved. Three-month-olds expected any continuous, bounded entity to move as a whole, and were not sensitive to configurational evidence that multiple entities were involved. Third, Spelke, Kestenbaum, Simons, & Wein (in press) found that young infants analyzed the path of motion to determine the number of objects behind screens. Infants were habituated to objects emerging, one at a time, from behind screens. If two screens are separated in space and if no object appeared between the screens, infants inferred that two distinct objects must be involved in the event.

Studies exploiting these paradigms converge in support of several generalizations concerning the bases of infants' object individuation. First, before 6 months of age, object individuation is based on physical knowledge of objects as bounded, coherent wholes that move on spatiotemporally continuous paths, subject to constraints of motion such as that one cannot pass through the space occupied by another, and that one cannot be in two places at the same time (see Spelke, Breinlinger, Macomber, & Jacobson, 1992 and Baillargeon, 1993 for reviews). Second, static configurational cues come to be exploited during the second half of the first year (Needham & Baillargeon, 1995; Schmidt, Spelke, & LaMorte, 1986; Spelke, et. al., 1993). Third, Needham & Baillargeon (1995) also showed that infants' understanding of the physical world overrides configurational information if these two sources of information conflict. For example, a box standing next to but sharing a boundary with a hose is perceived as two distinct objects by 8-month-olds, but when the hose appears to reply on the box for support, infants judged that the two are parts of a single object. Conversely, two octagons side by side, arranged such that a stripe seems to extend seamlessly from one through to the other, are perceived as one object by 8-month-olds, but if a thin plastic screen is inserted between the two and then removed, infants judged that two distinct objects made up the array.

In the terminology of philosophers such as Wiggins (1980), the physical knowledge young infants use in object individuation constitutes a sortal concept, *object*. Sortals are concepts which provide principles of individuation and numerical identity. For example, we know whether we are in the presence of one chair or two chairs and we use certain criteria to decide whether the chair we see today is the same one we saw yesterday. The criteria provided by the sortal *object* are spatiotemporal: One object cannot be at two places at the same time, two objects cannot be at the same place at the same time, and objects travel on spatiotemporally connected paths. The studies cited above demonstrate that the sortal, *object*, is in place in the first few months of life.

Xu & Carey (in press) provide evidence that infants do not begin to represent more specific sortals such as *ball, cup, bottle, book, duck,* and *truck* until some time between 10 and 12 months of age. These studies suggest that object kind information does not guide object individuation until the end of the first year. For example, in one of the experiments, 10-month-old infants were habituated to events in which a very familiar object, say, a ball, appeared from behind a screen and returned, then another very familiar object, say, a bottle, appeared from the other side of the screen, and then returned. The question was whether the infants would infer from the kind change that there must be two numerically distinct objects behind the screen. When the screen was removed, the infants were shown the expected outcome of two objects, namely a ball and a bottle, or the unexpected outcome of only one of the two objects, a ball or a bottle. Surprisingly, the 10-month-olds did not look longer at the unexpected outcome: their pattern of looking was identical to their preference for two objects on baseline trials, as if there was not sufficient information to make a judgment. In contrast, when 10-month-old infants were given spatiotemporal information by simply showing them the two objects simultaneously for a brief 2 or 3 seconds at the beginning of the familiarization event, 10-month-olds looked longer at the unexpected outcome of one object when the screen was removed.

It is not until 12 months of age that majority of the infants exhibited longer looking at the unexpected outcome of a single object, suggesting that they had inferred that there must be two distinct objects behind the screen. When infants succeed in the looking time version of this experiment at one year of age, they also succeed in a reaching task that provided a more direct measure of success (Xu, Carey, Raphaelidis, & Ginzbursky, 1995). In this experiment, 12-month-olds infants were trained to retrieve toys from a box that has a small opening on top. On the test trials, the infants were either shown two different objects being pulled out of the box one at a time or one object being pulled out twice. The dependent measure was how many times the infant reached into the box as an indication of how many things she thought was in the box. Xu et al. found that infants reached roughly twice when there were two toys and roughly once when there was only one toy in the box. They concluded that by 12 months of age, infants can use kind information to set up representations of two distinct objects and this representation is robust enough to support action.

Based on these studies, Xu & Carey concluded that infants may begin with one sortal/kind concept *object*, and the more specific sortals are acquired later in the first year of life. They dubbed this "the *Object*-first hypothesis."

Although various control experiments showed that Xu & Carey's method was sensitive, there is a lingering doubt about the claim that infants cannot use kind information in object individuation until about 12 months of age. To succeed in Xu & Carey's task infants must be able to recall the representation of the first object (including its features) upon seeing the second in order to set up a representation of two distinct individuals. If this memory requirement is too taxing for the 10-month-old infants, their failure could be due to a weakness in their information-processing capacity and not due to a difference between their and adults' conceptual representations.

The present study seeks a stronger test of the *Object*-first hypothesis by adapting Spelke et al.'s (1993) paradigm using objects that clearly belong to specific kinds. Consider the following display: A toy duck with a flat bottom perching on the flat top of a toy car (see Figure 1). The duck has all the typical features of a duck, e.g., a duck's bill, eyes, distinct shape, etc.; the car is a typical car with wheels, doors, metallic shine, etc. An adult perceives this display as unambiguous -- We perceive a duck sitting on top of a car and we do not expect the two objects to be connected. Gestalt principles do not clearly specify where the boundary of the objects is -- cues such as violation of good continuation and good form are fairly weak -- but our knowledge about specific kinds of objects tells us that there are two objects in this array.

In the present study, we use the duck-car display and ask whether 10-month-old infants can use object kind information to successfully individuate objects. The infants are habituated to a display that consists of a duck perching on top of a car with a hand suspended right above the display without touching it. During the test trials, the hand grasps the head of the duck and lifts it up. In the expected outcome, the duck is lifted but the car stays in place. In the unexpected outcome, the car is lifted along with the duck as if they were parts of one complex object. If infants have segregated the display into two objects, they should look longer at the unexpected outcome in which the car is lifted along with the duck. It is important to note that both objects are in plain view throughout the experiment, so the infants will not have to actively retrieve their representation of the first object upon seeing the second in order to set up a representation of two distinct objects. Given the findings of Xu & Carey (in press) and Xu et al. (1995), we predict that 10-month-old infants will fail to use the differences between the toy duck and the toy car to segregate the array into two distinct objects whereas 12-month-olds will succeed.

Before beginning the infant studies, Experiment 1 tested that our intuitions about adult perception of the display were correct.

Experiment 1

This experiment investigated how adults perceive the duck-on-top-of-car display which would be presented to infants. After viewing the duck-car display for 5 seconds, adults were asked to judge how many objects there were and what would happen if the duck underwent motion. The training trials and the procedure were adapted from Spelke et al. (1993).

Method

Participants

Twelve adults (5 female and 7 male) from the university staff and student community participated in the study. They ranged in age from 20 to 34 years (Mean age = 25). None of the subjects had taken a course in perception or had any knowledge of the current research with infants.

Materials

A white coffee mug and a metal fork were used in the training trials. Two toys were used in the test trial: A bright yellow toy duck with an orange bill, feet, and eyes and a fluorescent green toy car with blue and yellow wheels and orange and blue decals. The toy duck was approximately 6 cm x 6 cm x 9 cm in size and the toy car was 11 cm x 5 cm x 5 cm.

Design and Procedure

Subjects were seated about 66 cm from a puppet stage on which the display was placed. They were told that we were interested in adults' immediate impression of displays that we would present to infants. They would view each display for 5 seconds before answering questions. Each subject completed a three-page questionnaire.

The experimenter then went behind the empty stage and raised a curtain that covered the entire stage. After she quietly placed the display on the stage, the curtain was lowered.

There were two training trials. In the first one, an empty coffee mug was placed on the stage. Subjects viewed it for about 5 seconds and were asked a series of questions: 1) "How many objects do you see?" 2) "How strong is your impression of one object on this scale, where 1 means a very weak impression of one object and 7 means a very strong impression of one object?" 3) "Does this (pointing to the handle of the mug without touching it) appear to be connected to this (pointing to the bowl of the mug)?" 4) "How strong is your impression of a connection on this scale?" 5) "If I were to grasp this (pointing to the handle of the mug) and lift it from here to here (moving the finger about 10 cm above the initial position), what would happen to this (pointing to the bowl of the mug)?" 6) "How strong is your impression that it will move?" 7) "What object(s) do you see in this display?" Next the curtain was raised and then lowered to show the same mug containing a fork (only the upper half of it was visible). The same series of questions were asked. Instead of pointing to the handle of the mug, the connectedness questions were accompanied by pointing to the upper half of the fork.

The experimenter then raised the curtain to cover the stage, put on the duck-on-top-of-car display, and lowered the curtain. After viewing it for about 5 seconds, the same series of questions were asked. She pointed to the midpoint of the duck and the body of the car for the connectedness and motion questions. Otherwise the procedure was identical to the training trials.

Results

For the first training trial with the mug, all subjects wrote down "one object" when asked how many objects they saw. The mean rating for impression of one object was 6.5. All subjects said that the handle was connected to the bowl of the mug. The mean rating for impression of connection was 6.2. All subjects said the bowl would move if the handle was lifted. The mean rating for moving was 6.7. Finally all subjects reported that they saw "a (coffee) mug" or "a cup."

For the second training trial with the mug and the fork, all subjects reported they saw "two objects." Mean rating of strength of impression of one object was 1.7. Eleven of the 12 subjects reported that the fork and the mug did not appear to be connected; the remaining one said "maybe." The mean rating for connectedness was 1.8. All subjects reported that the mug would stay in place if the fork were lifted. The mean rating for motion was 1.7. All subjects reported that they saw "a mug/cup and a fork/spoon/utensil."

When shown the duck-car display, all subjects reported "two objects" when asked how many objects they saw. Subjects had a weak impression of one object; the mean rating for strength of impression of one object was 2.0, significantly different from the neutral rating of 4 ($t(11) = -9.381$, $p < .0001$). Eleven of the 12 subjects reported that the duck and the car were not connected; the remaining one said "maybe." The mean rating of the strength of connection was 2.0, significantly different from the neutral rating of 4 ($t(11) = -9.381$, $p < .0001$). All subjects reported that the car would stay in place if the duck were grasped and lifted up. The mean rating of strength of impression of the car moving was 2.5, significant different from the neutral rating of 4 ($t(11) = -3.924$, $p < .005$). All subjects reported that they saw "a toy/rubber duck and a toy car."

Discussion

Adults' verbal ratings showed that the duck-on-top-of-car display evoked clear and strong impression of two objects. The participants judged that the two objects were not connected and when the duck was lifted the car would remain in place. There was also no ambiguity as to which kinds the objects belonged to. In Experiments 2-4, we present the same display to infants.

Experiment 2

Experiment 2 addresses the question of whether infants can use object kind information to individuate objects, as did the adults in Experiment 1. Two experimental conditions were included. In the movement condition, the duck was moved laterally off the car, thus providing the infants with spatiotemporal evidence for two distinct objects. In the static condition, the infants were shown only the static array of the duck perched on the car, as in Experiment 1. Given the findings of Xu & Carey (in press), we expect that 10-month-old infants will succeed in using spatiotemporal information to individuate objects in the movement condition but they will fail to use kind information to do so in the static condition.

Method

Participants

Sixty full-term infants participated in the study (34 boys and 26 girls), ranging from 9 months 12 days to 10 months 20 days (mean age 10 months, 3 days). Equal numbers of infants were randomly assigned to one of three conditions (mean ages were 10 months 6 days for the static condition, 10 months 0 days for the movement condition, and 10 months 2 days for the baseline condition). Five additional infants were excluded from the sample due to fussiness (2), experimenter error (2), or equipment failure (1). All infants were recruited by obtaining their birth records from town halls in the Greater Boston area and subsequently contacting their parents by mail and telephone. Participation was compensated by a token gift (a T-shirt, a bib, or a sippy cup) with a university logo.

Materials

The same toy duck and toy car used in Expt. 1 were used in this experiment. An informal survey with parents showed that both kinds of toys were familiar to 10-month-olds.

Apparatus

The events were presented on a three-sided, 76 cm x 31 cm x 13 cm, stage with a light blue top surface. A black curtain hung behind the stage to make the object and background contrast prominent and to conceal the movement of the experimenter. Another black curtain hung over the front part of the stage to conceal the video camera under the stage as well as to prevent the experimenter from seeing the infant's face. The actual display area measured 76 cm in width and 24 cm in height. Black curtains also concealed the observer, who sat to the right of the stage and monitored the infant's looking. The observer could not see what was presented on the stage and was blind to which condition the infant was in. A push button was connected to a microcomputer which recorded the looking times. White noise masked any sounds produced by the movements of the experimenter.

The stage was lit from above and from the two sides; otherwise the room was dark. The infant sat in a high chair, about 66 cm from the stage, with eye level slightly above (about 5 cm) the floor of the stage. The parent sat next to the infant with his/her back toward the stage, and was instructed not to look at the displays, so as not to influence the infant's response, and not to attempt to draw the infant's attention in any way. The parent was instructed to "smile and be natural" whenever the infant looked at him or her.

A video camera was set up under the stage, focusing on the infant's face and recording the entire session. The videotape record provides no information about what is presented on the stage so an observer scoring from the videotapes will be completely blind to the condition or the order of the trials.

Design and Procedure

Equal number of infants participated in three conditions: static condition, movement condition, and baseline condition.

After the infant and the parent were seated, the experimenter turned on the video camera. The experimenter then tapped or waved on the center top, the center bottom, and both ends of the stage to draw the infant's attention to the empty stage as well as to define the window of looking for the observer. During this calibration process and throughout the experiment, only the experimenter's hand was visible to the infant.

Static Condition.

Habituation phase. For each habituation trial, a black curtain was raised to cover the entire stage area from view. After a three second pause (the time required to change displays in the test trials), the curtain was lowered to show the toy duck sitting on top of the toy car (see Figure 1). The experimenter then reached in with her right hand, stopping about 2 cm right above the head of the duck. When the hand stopped, the experimenter drew the infant's attention, "Look at this, [infant's name]. Now." The word "now" was used to signal the observer to start timing in all trials. The infant's looking was then monitored. A trial ended when the infant looked away for two continuous seconds after looking for at least 0.5 second, as determined by the release of the observer's button. At the end of the trial, the experimenter lifted her hand, then the curtain was raised to cover the stage. After a three second pause the curtain was lowered and the next trial began. The habituation criterion was defined as the sum of looking time of the last three trials being half or less than the sum of looking time of the first three habituation trials, where the sum of the first three trials was greater or equal to 12 seconds. Habituation trials continued until the infant met the habituation criterion or until 14 trials have been completed.

Half of the infants saw the duck-car display where the duck was glued onto the car (this is how the unexpected outcome was created) during habituation; half saw just a duck perching on top of a car. An informal survey showed that adults could not discriminate these two displays.

These habituation trials familiarized the infant with the objects and the presence of a human hand. They also encouraged the infant to anticipate the test event when the hand grasped the duck and lifted it.

Test phase. When the habituation trials ended, the curtain was again raised to cover the stage. After a 3 second pause, the test trials began. The curtain was lowered to reveal the duck-car display. The experimenter reached in and grasped the top of the duck's head and lifted it 7 cm vertically at the speed of about 7 cm/sec. The hand then stopped in midair, holding the top of the duck. The infant's attention was then drawn, "Look, [infant's name]" and looking time was monitored. After the infant looked away, the hand put down the duck (or the duck and the car) onto the stage floor and the curtain was raised to cover the entire stage. After a 3 second pause the next test trial began. The infant saw two outcomes alternately. In the expected outcome (for adults), the duck was lifted and suspended in midair while the car stayed stationary on the stage. In the unexpected outcome (for adults), the duck as well as the car were lifted and suspended in midair together (see Figure 1). There were six test trials for each infant. The order of outcome was counterbalanced across subjects.

Insert Figure 1 about here.

Movement Condition.

Habituation phase. The habituation trials in the movement condition were the same as the ones in the static condition with one important difference. During each trial, after the curtain was lowered, the hand reached in, grasped the top of the duck's head, and slid the duck off the car horizontally about 10 cm such that the bottom of the duck no long overlapped with the top of the car. The duck was then returned to its initial position. The hand then stopped about 2 cm above the head of the duck as in the static condition. The infant's attention was drawn, "Look, [baby's name]," and looking time was monitored. All other details of the habituation phase were the same as in the static condition.

Test phase. The test trials in the movement condition were identical with those of the static condition. There were six trials and the order of outcome was counterbalanced across subjects.

Baseline Condition.

The baseline condition measured whether infants had an intrinsic preference for either of the outcome display. Infants were shown the outcomes of the six test trials. They never saw the display resting on the floor of the stage. Each time when the curtain was lowered, the infant saw the final outcome of a test trial: a hand holding the duck in midair with the car stationary on the floor of the stage, or the duck and the car in midair. The infant's looking time was recorded. The order of outcome was counterbalanced across subjects.

Results

Fifty-five of the 60 infants in this study were off-line observed by an observer who was completely blind to the condition and order of outcomes of the experiment (the remaining 5 infants were not on video due to experimenter error or equipment failure). Interscorer reliability was 93.0%.

The principal findings are shown in Figure 2. An alpha level of .05 was used for all statistical tests. Initial ANOVAs revealed no effects of sex, order of outcome, or whether the infants saw the glued-together display during habituation. Subsequent analyses collapsed over these factors.

Insert Figure 2 about here.

The main results of Experiment 2 were that the infants had a small preference for the apart outcome in the baseline, and they failed to overcome this preference in the static condition but succeeded in doing so in the movement condition.

Static Condition.

Habituation trials. The average number of habituation trials was 8.8. One infant reached the maximum of 14 trials.

Test trials. An analysis of variance compared the looking times in the static condition and the baseline condition with condition (baseline vs. static) as a between-subject variable and outcome (apart vs. together) as a within-subject variable. There was a main effect of condition. Infants looked overall longer in the baseline condition ($M = 11.8$ s, $SD = 6.2$) than in the static condition ($M = 7.4$ s, $SD = 3.3$), $F(1,38) = 10.732$, $p < .005$, presumably because in the baseline infants did not go through a habituation phase. There was also a marginally significant main effect of outcome. Infants looked overall longer at the apart outcome (M_a = 10.4 s,[1] SD = 5.5) than the together outcome (M_t = 8.8 s, SD = 5.3), F(1,38) = 4.007, p = .052. However, there was no interaction between these two variables, F(1,38) = .201, p = .657. Infants showed the same preference for the apart outcome in the test trials as in the baseline trials (baseline: M_t = 10.9 s, SD = 6.1; M_a = 12.8 s, SD = 6.4; static: M_t = 6.8 s, SD = 3.5; M_a = 8.0 s, SD = 3.1). This pattern of looking was consistent across all three pairs of test trials of the static condition (Pair 1: M_t = 8.8 s, M_a = 10.4 s; Pair 2: M_t = 6.4 s, M_a = 7.5 s; Pair 3: M_t = 5.1 s, M_a = 6.2 s). In sum, the infants did not look longer at the unexpected outcome of the two objects moving together in the static condition. They exhibited a pattern of looking that did not differ from the infants in the baseline condition.

Non-parametric tests confirmed the above results. Fifteen out of 20 infants in the baseline condition and 13 out of 20 infants in the static condition looked longer at the apart outcome. A Mann-Whitney-U test showed that these two conditions did not differ from each other (z = -1.15, p = .25).

Movement Condition.

Habituation trials. The average number of habituation trials was 8.7. Two infants reached the maximum of 14 trials. A t-test comparing number of habituation trials of the static and movement conditions revealed no difference, t(18) = .565, p = .89.

Test trials. An analysis of variance examined the effects of condition (baseline vs. movement) and outcome (apart vs. together). There was a main effect of condition. Overall infants looked longer in the baseline (M = 11.8 s, SD = 6.2) than in the test trials (M = 7.6 s, SD = 4.7), F(1,38) = 8.021, p < .01, presumably

---

[1] Throughout the paper, M_a is the mean for the apart outcome and M_t is the mean for the together outcome.

because the baseline infants did not go through a habituation phase. More importantly, there was an interaction between condition and outcome, $F(1,38) = 4.494$, $p < .05$. That is, the preference for the apart outcome in the baseline has been reversed in the test trials (Baseline: $M_t = 10.9$ s, $SD = 6.1$; $M_a = 12.8$ s, $SD = 6.4$; Movement: $M_t = 8.5$ s, $SD = 5.8$; $M_a = 6.7$ s, $SD = 3.2$). The infants looked longer at the unexpected outcome of the two objects moving together in the test trials of the movement condition. This pattern of result holds for all three test trial pairs in the movement condition (Pair 1: $M_t = 13.6$ s, $M_a = 9.0$ s; Pair 2: $M_t = 6.4$ s, $M_a = 6.3$ s; Pair 3: $M_t = 5.5$ s, $M_a = 4.8$ s).

Non-parametric test confirmed the above results. Fifteen out of 20 infants looked longer at the apart outcome in the baseline condition whereas only 6 of the 20 infants did so in the spatiotemporal condition. A Mann-Whitney-U test showed that these two conditions differed from each other, $z = -2.326$, $p = .02$.

Most importantly, a third ANOVA compared the looking times of the static and movement conditions with condition and outcome as variables. There was an interaction between these two variables, $F(1,38) = 4.659$, $p < .04$. The infants in the movement condition looked longer at the unexpected outcome of the objects moving together while those in the static condition did not do so. A Mann-Whitney-U test confirmed the above result non-parametrically, $z = -2.273$, $p = .02$.

Discussion

The results of Experiment 2 were consistent with our prediction: The infants failed to use kind information in object individuation but succeeded in using spatiotemporal information. In the kind condition, infants' looking time pattern was not different from that of the baseline condition. Infants behaved as if they had no clear expectations about whether the car should move along with the duck or not. In contrast, the infants in the spatiotemporal condition overcame their baseline preference for the apart outcome and looked longer at the unexpected outcome of the two objects moving together.

It may be possible that although 10-month-olds are familiar with toy ducks and toy cars in general, they may need some experience with the specific toys we used in this experiment. In Experiment 3, we allowed the infant play with each toy before the testing. This manipulation ensured that the infants had clear representations of the shape of the toys. If 10-month-olds truly have not yet represented the sortals *duck* and *car* and only represented these toys as objects with duck- or car-properties, then more exposure with each toy, one at a time, should not change the pattern of results.

Experiment 3

In this experiment, we sought to replicate and extend the findings of Experiment 2 by allowing the infants to manipulate the objects prior to the habituation phase. Again, we contrasted two conditions: the static condition and the movement condition.

Method

Participants

Forty full-term infants participated in this study (18 girls, 22 boys) with a mean age of 10 months, 3 days, ranging from 9 months, 16 days, to 10 months, 18 days. Equal number of infants were randomly assigned to two conditions (mean ages were 10 months, 5 days for the static condition and 10 months, 1 day for the movement condition). All infants were recruited from the Greater Boston area as in Experiment 1. Six additional infants were eliminated from the sample due to fussiness (5) or experimenter error (1).

Materials and Apparatus

The same puppet stage and stimuli were used in Experiment 3 as in Experiment 2. The setup was identical to that of Experiment 2.

Design and Procedure

Baseline Condition.

The baseline was taken from Experiment 2. The infants were shown the final outcomes of the test trials without habituation.

Static Condition.

The procedure for this condition was identical to the procedure in the corresponding condition of Experiment 2, except for one important difference. After the infant and the parent were seated and prior to drawing the infant's attention to the stage, the experimenter brought out the duck and the car, one at a time, to the infant and let the infant play with each toy for about 30 seconds. The infants never saw the two objects at the same time. The first object was removed from view before the second one was introduced. All infants were required to at least touch each object; the vast majority of them took the objects in their hands and manipulated/mouthed them. Almost all infants became bored with the toy by the end of the 30 second period. The order of which object was introduced first was counterbalanced across subjects.

The procedure then unfolded exactly as in the static condition of Experiment 2. The infants were habituated to the stationary display of the duck perching on top of the car, then they were shown six test trials, alternating between the apart (expected) and together (unexpected) outcomes.

Movement Condition.

The procedure for this condition was exactly the same as in the movement condition of Experiment 2 with one important difference. Prior to drawing the infant's attention to the stage, the experimenter brought out the duck and the car, simultaneously, to the infant and let the infant play with them. The infant was given each toy (with the other one in view) for about 20 seconds, then she was given both toys for another 20 seconds. Infants' attention was drawn to each toy while the other was in view; the vast majority of the infants spontaneously grasped both toys. Almost all infants became bored with the toys by the end of the 60 second period.

The rest of the procedure was identical to that of the movement condition of Experiment 2. The infants were habituated to the stationary display, then they were shown six test trials, alternating between the apart and together outcomes.

<u>Results</u>

Thirty-two of the 40 infants in this study were off-line observed by an observer who was completely blind to the condition and order of outcome of the experiment. The remaining 8 infants were not on video due to experimenter error or equipment failure. Interscorer reliability was 92.2%.

The main findings of Experiment 2 are shown in Figure 3.

Insert Figure 3 about here.

The results were essentially identical to those of Experiment 2, even though infants were allowed to manipulate the objects beforehand. In the static condition, infants still failed to overcome their baseline preference and looked longer at the apart (expected) outcome whereas in the movement condition, they succeeded in overcoming the baseline preference and looked longer at the together (unexpected) outcome.

An alpha level of .05 was used in all statistical tests. Initial ANOVAs revealed no effects of sex, order of outcome, or whether the infant saw the glued-together display during habituation. Subsequent analyses collapsed over these factors.

<u>Static Condition.</u>

Habituation trials. On average, it took infants 8.5 trials to habituate to the stationary display. Three infants reached the maximum of 14 trials.

Test trials. An analysis of variance compared the looking times in the static condition with the baseline condition with condition (baseline vs. static) as a between-subject variable and outcome (apart vs. together) as a within-subject variable. There was a main effect of condition. Infants looked longer overall in the baseline (M = 11.8 s, SD = 6.2) than in the static condition (M = 8.2 s, SD = 3.2), $F(1,38) = 7.550$, $p < .01$. There was also a marginally significant effect of outcome. Overall infants looked longer at the apart outcome (M_a = 10.8 s, SD = 5.3) than the together outcome (M_t = 9.2 s, SD = 5.2), $F(1,38) = 3.601$, $p = .065$. More importantly, there was no interaction between the two variables, $F(1,38) = .274$, $p = .604$. Infants looked longer at the apart outcome in both the baseline and the static conditions (baseline: M_t = 10.9 s, SD = 6.1; M_a = 12.8 s, SD = 6.4; static: M_t = 7.6 s, SD = 3.6; M_a = 8.7 s, SD = 2.6). This pattern of results holds for the first two pairs of test trials of the static condition (Pair 1: M_t = 8.4 s, M_a = 12.0 s; Pair 2: M_t = 6.9 s, M_a = 7.1 s; Pair 3: M_t = 7.6 s, M_a = 7.1 s).

Non-parametric tests confirmed the above results. Fifteen out of 20 infants in the baseline and 14 out of 20 infants in the static condition looked longer at the apart outcome (Mann-Whitney-U, $z = -1.014$, $p = .31$).

Movement Condition.

Habituation trials. The average number of habituation trials was 8.0. Two infants reached the maximum of 14 trials. A t-test comparing the number of habituation trials between the static and movement conditions revealed no difference, $t(18) = -2.26$, $p = .70$.

Test trials. An analysis of variance compared the looking times with condition (baseline vs. movement) and outcome (apart vs. together) as variables. As before, there was a main effect of condition. Infants looked longer in the baseline condition ($M = 11.8$ s) than in the spatiotemporal condition ($M = 6.0$ s), $F(1,38) = 19.797$, $p < .0001$. There was also a marginally significant interaction between the two variables, $F(1,38)$ 3.481, $p = .07$. Infants were able to overcome their baseline preference for the apart outcome; they looked longer at the together (unexpected) outcome on the test trials (baseline: $M_t = 10.9$ s, $SD = 6.1$; $M_a = 12.8$ s, $SD = 6.4$; movement: $M_t = 6.4$ s, $SD = 2.7$; $M_a = 5.6$ s, $SD = 2.7$). This pattern of results holds for two of the three test trial pairs of the movement condition (Pair 1: $M_t = 7.6$ s, $M_a = 6.5$ s; Pair 2: $M_t = 5.5$ s, $M_a = 5.6$ s; Pair 3: $M_t = 6.2$ s, $M_a = 4.7$ s).

Non-parametric tests corroborated the above results. Fifteen out of 20 infants in the baseline looked longer at the apart outcome, whereas only 6 out of 20 infants did so in the spatiotemporal condition (Mann-Whitney-U, $z = -2.326$, $p = .02$).

More importantly, a third ANOVA compared the looking times of the static condition and the movement condition with condition and outcome as variables. There was a main effect of condition. Infants in the static condition ($M = 8.2$ s) looked longer overall than the infants in the movement condition ($M = 6.0$ s), $F(1,38) = 8.583$, $p < .01$. Most importantly, there was a marginally significant interaction between condition and outcome, $F(1,38) = 3.329$, $p = .076$. Non-parametric test confirmed that the distribution of looking time between the two groups was significantly different from each other (Mann-Whitney-U $z = -2.07$, $p < .04$).

Although on parametric tests the effects of interests in the test conditions were only marginally significant, it was clear that the pattern of results in Experiment 3 did not differ from that of Experiment 2. This was confirmed by an analysis of variance with experiment (2 vs. 3), condition (baseline vs. static vs. movement) and outcome (apart vs. together) as variables. This analysis revealed no effect of experiment ($F(1,114) = 0.066$, $p = .798$) and no three-way interaction ($F(2,114) = 0.164$, $p = .849$).

Having noticed that the average number of habituation trials in the static condition of this experiment (8.5) did not seem to differ from the number of habituation trials in the static condition of Experiment 2 (8.8), we decided to run two other statistical tests comparing these two versions of the static condition. A t-test comparing the number of habituation trials revealed no difference between the two conditions, $t(19) = .2991$, $p = .77$; a second t-test comparing the habituation criterion of the two conditions also revealed no difference, $t(19) = .8212$, $p = .42$.

Discussion

Experiment 3 replicated and extended the findings of Experiment 2. Although the infants were allowed to play with the objects prior to testing, they exhibited the same pattern of looking as in Experiment 2. Infants in the static condition still failed to look longer at the unexpected outcome of the duck and the car moving together; their looking time pattern was not different from the baseline preference of looking longer at the apart outcome. In contrast, the infants in the movement condition succeeded in looking longer at the unexpected outcome of moving together.

It is telling that the number of habituation trials and the habituation criterion in the static condition of Experiment 3 did not differ from those of the corresponding condition in Experiment 2. That is, having manipulated the objects for 30 seconds each, it took the infants the same amount of time to habituate to the duck-car display as in Experiment 2. There are two possible explanations. Perhaps the reason why the manipulation did not help was because the infants did not have the necessary memory capacity to make use of this information. However, Baillargeon, Graber, & Devos (1989) found that 8-

month-olds can remember the location of a hidden object after a 70-second delay and Meltzoff (1988) found that 9-month-olds can remember the specific actions performed on various objects after a 24-hour delay. Given these findings, we think it is unlikely that the infants' failure to use the additional manipulation information was due to memory limitations. The second explanation is that this finding is a reflection of the conceptual difference between 10-month-old infants and adults. The infants did not connect the representations established while manipulating each object with the representation of the duck-car display. This is consistent with the *Object*-first hypothesis: If the infants represented the duck and the car as objects with duck- or car-properties, these representations would not help with the duck-car display, which can be seen as an object with duck- and car-properties. It is only when infants are shown that the objects move relative to one another that they represent them as distinct objects. Thus, we attribute the infants' failure to their not representing object kinds such as *duck* and *car*; they must see the two objects move with respect to each other in order to represent them as two distinct objects.

Experiments 2 & 3 place virtually no memory demands upon the infant, and yet they support Xu & Carey's (in press) hypothesis that 10-month-old infants use spatiotemporal but not kind information in object individuation. In other words, 10-month-old infants do not represent the specific sortals *duck* and *car*, consistent with the hypothesis that 10-month-olds have not constructed sortals more specific than *object*.

Twelve-month-old infants succeeded in Xu & Carey's (in press) looking paradigm as well as in Xu et al.'s (1995) reaching paradigm. Experiment 4 tests the prediction that 12-month-olds' will succeed under the conditions of Experiment 3, using kind information given by the static display.

Experiment 4

Experiment 4 is a replication of the static condition of Experiment 3 with 12-month-olds. In addition, a baseline condition was run.

Method

Participants

Forty full-term infants participated in this study (17 girls, 23 boys) with a mean age of 12 months, 13 days, ranging from 12 months 1 day to 12 months 25 days. Equal number of infants were randomly assigned to either the baseline or the static condition (mean age 12 months, 15 days and 12 months, 11 days, respectively). All infants were recruited from the Greater Boston area as in Expts. 2 & 3. None had participated in Experiment 2 or 3. Additional 6 infants were excluded due to fussiness (4), parental interference (1), or experimenter error (1).

Materials and Apparatus

The materials and apparatus were identical to those in Expts. 2 & 3.

Procedure

Baseline Condition.

The procedure for this condition was identical to the baseline condition in Expt. 2.

Static Condition.

The procedure was identical to the static condition of Expt. 3, except for one modification. Previous studies have shown that full habituation procedure was too long for 12-month-olds, therefore we used a fixed number of familiarization trials. Each infant was shown the stationary display 6 times.

Results

Thirty-six of the 40 infants were off-line observed by an observer who was completely blind to the order of outcome (the remaining 4 infants did not have a camera record due to equipment failure). The interscorer reliability averaged 94.1%.

The main finding of Experiment 4 was that compared to their baseline preference, 12-month-olds looked longer at the unexpected outcome of the two objects moving together (Figure 4).

Insert Figure 4 about here.

An alpha level of .05 was used for all statistical tests. An analysis of variance on looking times was performed with condition (baseline vs. static) and outcome (apart vs. together) as variables. There was an interaction between the two variables, $F(1,38) = 7.118$, $p < .02$. The infants looked slightly longer at the apart outcome in the baseline; they reversed that preference in the static condition and looked longer at the unexpected outcome of moving together (baseline: $M_t = 8.2$ s, SD = 3.8; $M_a = 9.8$ s, SD = 4.5; static condition: $M_t = 10.8$ s, SD = 5.4; $M_a = 8.5$ s, SD = 3.9). The preference for the unexpected outcome holds for all three pairs of test trials in the static condition (Pair 1: $M_t = 14.3$ s, $M_a = 10.0$ s; Pair 2: $M_t = 9.7$ s, $M_a = 8.5$ s; Pair 3: $M_t = 8.0$ s, $M_a = 6.1$ s).

Non-parametric tests confirmed the above results. Thirteen of the 20 infants looked longer at the apart outcome in the baseline whereas only 4 of the 20 infants did so in the static condition. A Mann-Whitney-U test showed that the two groups were significantly different from each other ($z = -2.57$, $p = .01$).

<u>Discussion</u>

The main finding of Experiment 4 was that infants succeeded in using kind information in object individuation at 12 months of age, which converges nicely with the findings of Xu & Carey (in press) and Xu et al. (1995). This convergence suggests that it is likely that the same underlying mechanism enables the infant to succeed at all three tasks.

General Discussion

The present studies provide further evidence for the hypothesis that 10-month-old infants do not use object kind information to individuate objects whereas they succeed in using spatiotemporal information to do so. Experiment 1 showed that the duck-car display evoked a clear and strong perception of two objects in adults. Yet in Experiment 2, when 10-month-olds were only shown the stationary display of a duck perched on top of a car, they did not have any expectations about whether the car should be lifted along with the duck. However, when they were shown that the duck moved independently relative to the car during habituation, they looked longer when the two objects moved together. More strikingly, in Experiment 3, the infants were allowed to manipulate each object before habituation to ensure a better representation of the shapes of the objects. However, this manipulation did not affect the habituation rate or the looking time pattern on the test trials, which suggests that the representations established when playing with each object was not connected with the representation established when shown the duck-car display on the stage. In Experiment 4, we showed that by 12 months of age, infants were able to use object kind information to successfully parse the duck-car display into two distinct objects.

Two experimental paradigms studying object individuation, Xu & Carey (in press) and the present studies, converge that 10-month-old infants use spatiotemporal information but not familiar object kinds to individuate objects; three experimental paradigms, Xu & Carey (in press), Xu et al. (1995), and the present studies, have shown that by 12 months, infants succeed robustly in using object kind to achieve object individuation on both looking time and reaching measures. These studies are consistent with the *Object*-first hypothesis, that is, infants may start off representing only one sortal concept, *object*, and more specific sortals such as *duck* and *car* are acquired later. Since the developmental change occurs in the same time window on both the Xu & Carey task and the present one, it seems likely that one underlying mechanism may be responsible for the change in both.

Two alternative interpretations of the present results may be raised. One is that perhaps the stimuli we chose were inadequate: After all, the present studies only used two stimuli, a toy duck and a toy car. However, parents judged that these objects were familiar to 10-month-old infants and the contrast we have chosen was very sharp -- the two objects differed in color, texture, and shape as well as in global category, animate vs. artifact/vehicle (Mandler & Bauer, 1988; Mandler, Bauer, & McDonough, 1991). Moreover, Xu & Carey (in press) have surveyed a wider range of stimuli highly familiar to 10-month-olds, e.g., ball, cup, bottle, book, elephant, truck, etc., and found that the infants consistently failed to use object kind information to establish two distinct individuals.

The second alternative interpretation is that perhaps the infants were confused by the top-bottom relation. After all, some of them may have seen pull-toys in which an animal is connected to a vehicle. We think this is unlikely. First, the display we used evoked very clear judgments from adults, who presumably have had much more experience with people or animals connected with vehicles. Second, for 10-month-old infants, the display of a duck perching on top of a car instead of sitting in a car is probably not a common one. Third, if the top-bottom relation is confusing, it would be hard to explain why 12-month-olds succeed robustly -- presumably the older infants have had more experience in general with pull-toys in which people or animals are connected to vehicles.

Tentatively, we conclude that sortal concepts at the level of *cup, car, duck, bottle,* etc. are not constructed until the last few months of the first year. These findings have implications for the interpretation of studies in the infant habituation literature. Several studies have shown that infants as young as 3 or 4 months can establish categories such as toy duck, car, or table (e.g., Cohen & Younger, 1983; Quinn & Eimas, 1993; Eimas & Quinn, 1994). In one experimental paradigm, infants are habituated to discriminable exemplars of a given category such as duck, then they dishabituated to an exemplar from a novel category such as cup while remaining habituated to a new exemplar from the familiar category. In a slightly different paradigm, young infants are familiarized to pairs of exemplars from a given category, say horse, they then devote more time looking at an exemplar from a different category, say chair, than a new exemplar from the familiar category. These results are sometimes interpreted as evidence that infants represent the concepts that underlie count nouns (e.g., basic-level kinds; cf. Macnamara, 1987; Roberts & Horowitz, 1986; global kinds, Mandler, Bauer, & McDonough, 1991). Xu & Carey (in press) and the present findings suggest that the habituation studies may reflect infants' sensitivity to duck- and cup-shape, or duck- and cup-properties, but the infants did not encode each exemplar of duck or cup as distinct individuals (i.e., a duck, another duck, a third duck ... a cup that is a distinct object from the ducks). It is only when infants represent distinct individuals such as ducks and cups are we warranted to conclude that they represent the concepts that underlie natural language count nouns.

Needham & Baillargeon (1995), Spelke, et al. (1993), Xu & Carey (in press), and the present studies together raise an interesting possibility about the developmental course of object individuation: These data suggest that infants may begin using gestalt relations in object segregation before being able to use object kind information. Contrary to Spelke et al.'s (1993) conjecture, gestalt relations may not be abstracted from learning about particular kinds of objects. Infants may engage in some correlational analysis of features to arrive at the gestalt principles.

Taken together the present studies with earlier studies by Kellman & Spelke (1983), Kellman (1984), Kellman, Spelke, & Short (1986), Kellman (1993), Needham & Baillargeon (1995), Spelke, Hosften, & Kestenbaum (1985), Streri & Spelke (1988), and Xu & Carey (in press), a broad generalization emerges: Spatiotemporal or kinetic information is the privileged source of information used by infants to segregate the world into three-dimensional distinct physical objects early on. Other sources of information such as gestalt principles or knowledge about object kinds may come to influence object individuation later in the first year of life.

There may be evolutionary as well as learnability reasons for why this is the case. Kellman (1993) argues that we may be evolved to use spatiotemporal or kinematic information early on for two reasons. First, in the natural world it is almost impossible for two distinct/unconnected objects to move together by accident. Thus it is a safe assumption that if the spatiotemporal evidence suggests that two pieces move together, they are parts of the same object. Second, configurational information is rather unreliable compared to kinematic information. Depending on what kind of objects we encounter, the rules of object segregation may vary. In other words, kinematic information is ecologically more valid than any configurational information. Similarly, Xu & Carey (in press) argue that using object kind information in object individuation depends on having learned that for different kinds of objects certain featural changes indicate change of identity while others do not. Presumably this knowledge is acquired through interactions with the real world. The infants need to represent some individuals that they can trace over time in order to observe the featural changes that occur; these early individuals are given by the spatiotemporal criteria.

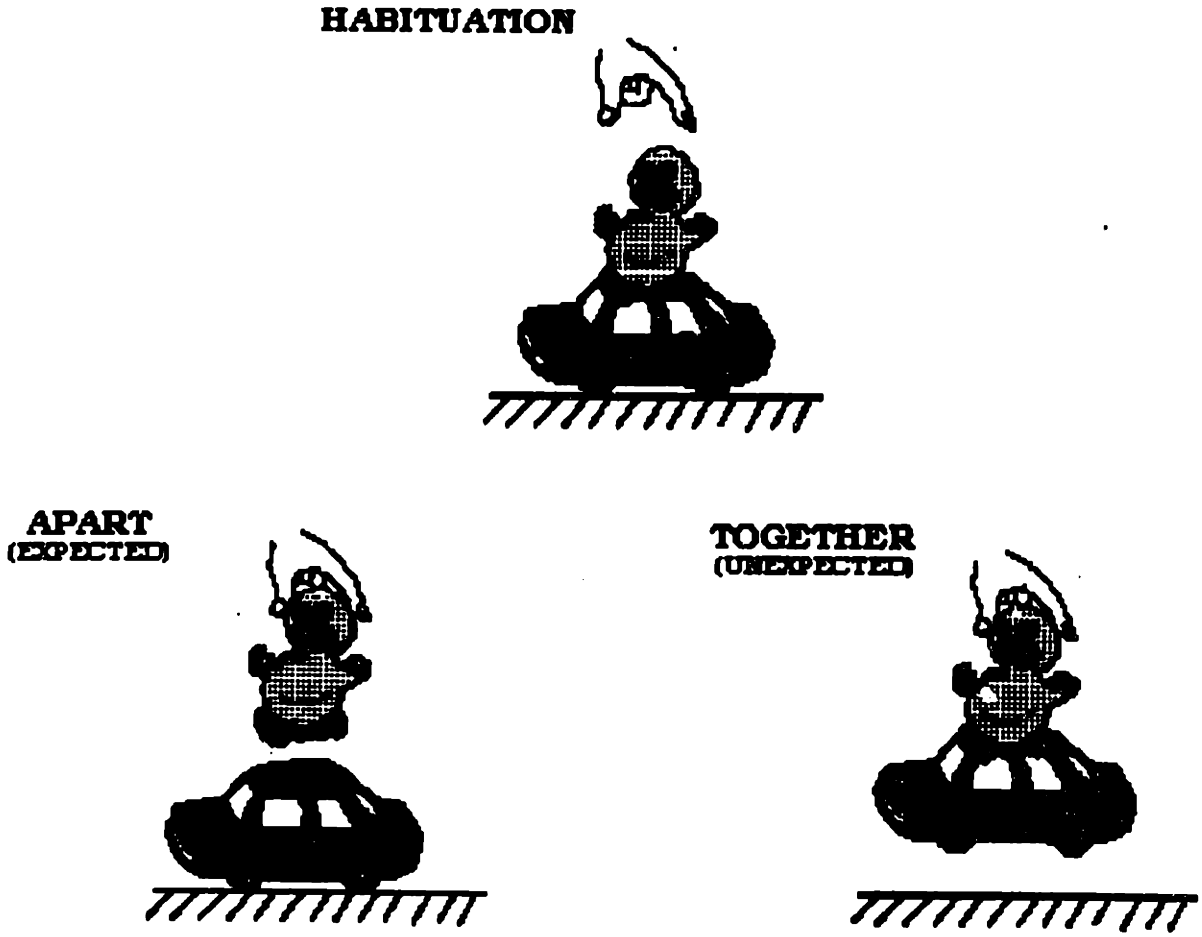


Figure 1

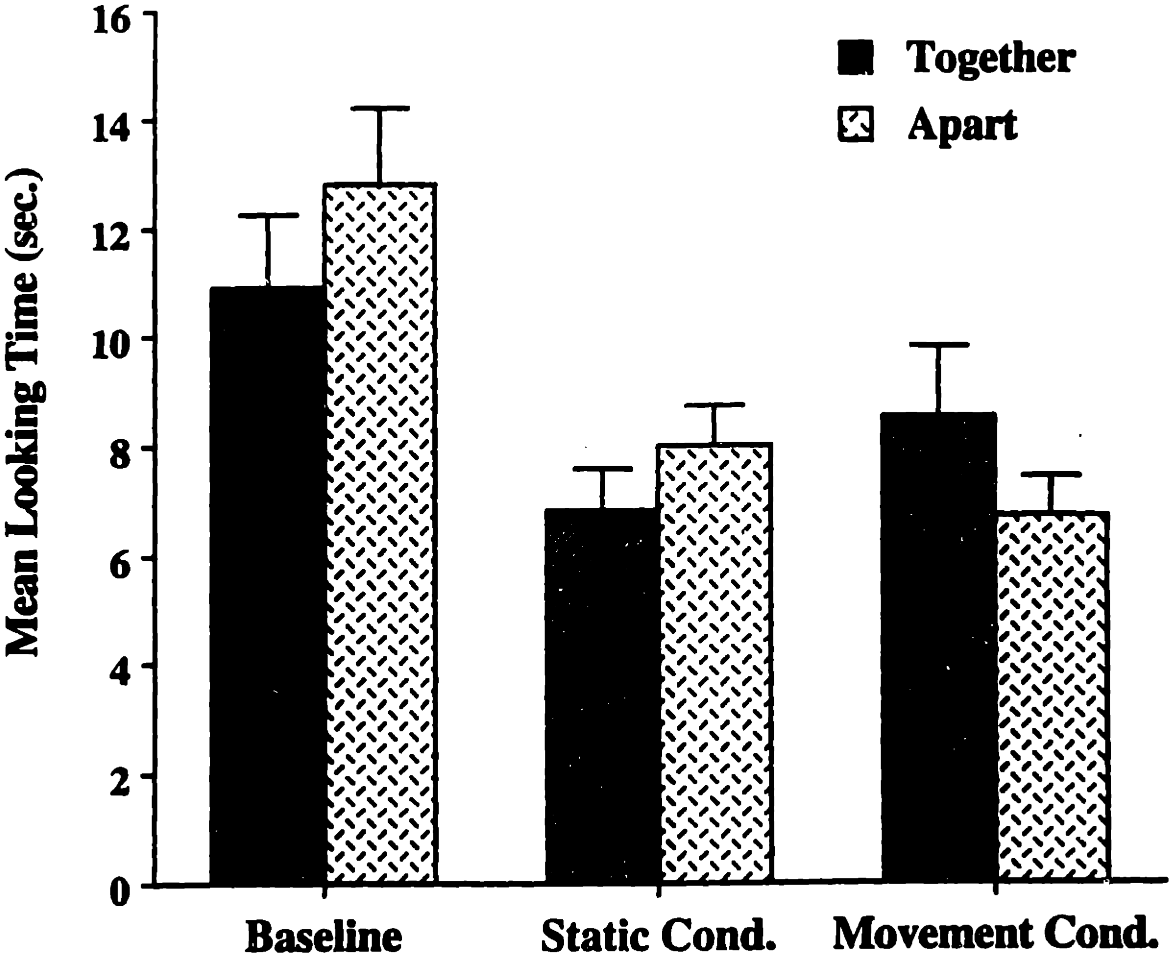

16
14
12
10
8
6
4
2
0
Mean Looking Time (sec.)
Together
Apart
Baseline
Static Cond.
Movement Cond.

Figure 2

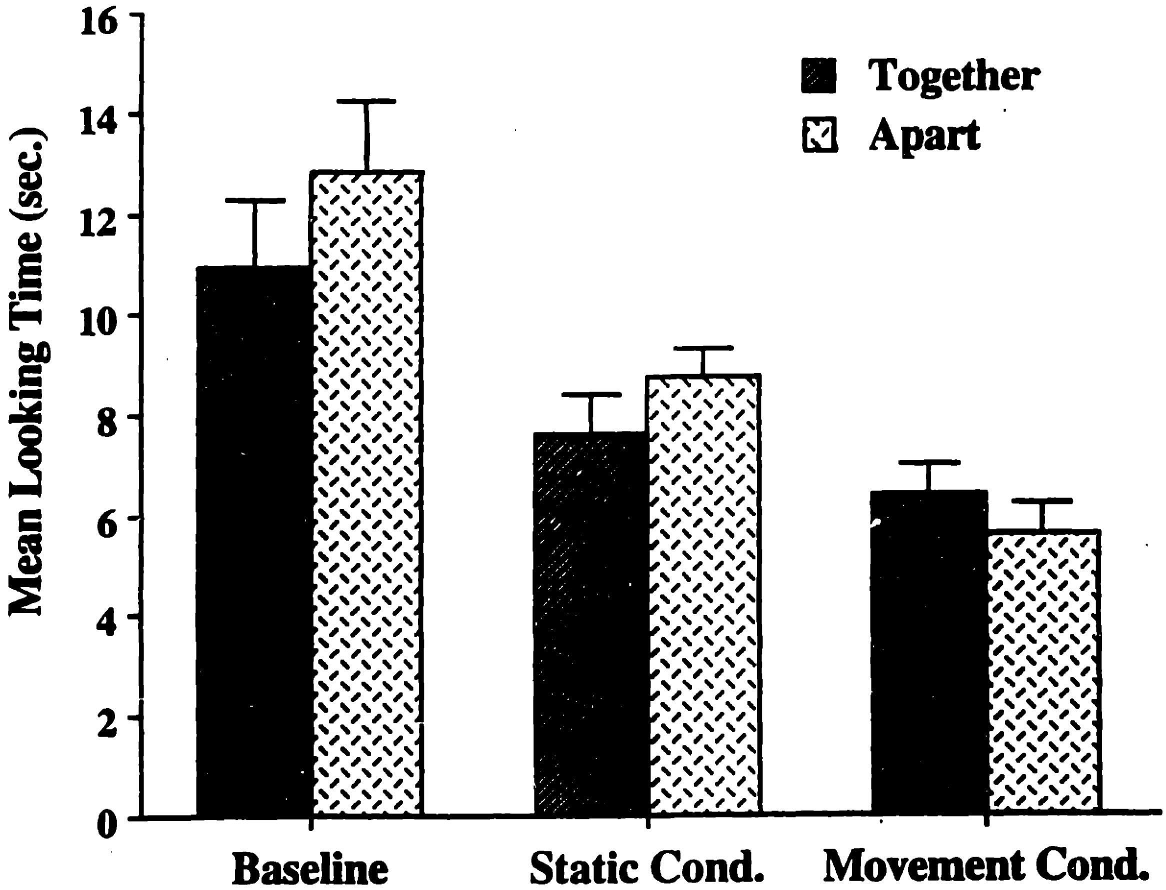
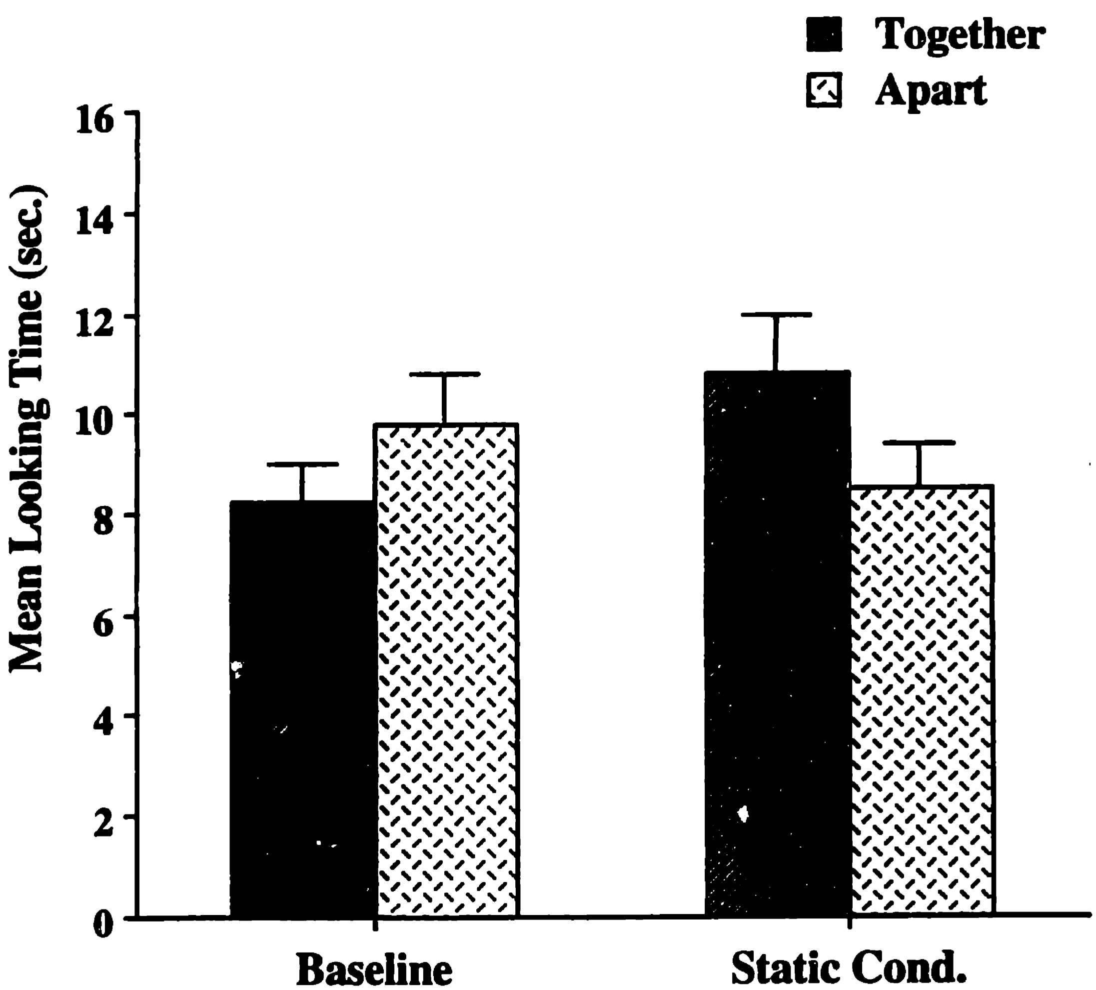

16
14
12
10
8
6
4
2
0
Mean Looking Time (sec.)
Together
Apart
Baseline
Static Cond.
Movement Cond.

Figure 3



Together
Apart
Mean Looking Time (sec.)
16
14
12
10
8
6
4
2
0
Baseline
Static Cond.

Figure 4

References

Baillargeon, R. (1987) Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology*, 23, 655-664.

Baillargeon, R. (1993) The object concept revisited. In C. Granrud (Ed.), *Visual perception and cognition and infancy.* Lawrence Erlbaum: Hillsdale, NJ.

Baillargeon, R. (1994) A model of physical reasoning in infancy. In C. Rovee-Collier and L. Lipsitt (eds.), *Advances in infancy research*, Vol. 9. Norwood, N.J.: Ablex.

Baillargeon, R. & DeVos, J. (1991) Object permanence in young infants: further evidence. *Child Development*, 62, 1227-1246.

Baillargeon, R., DeVos, J., & Graber, M. (1989) Location memory in 8-month-old infants in a non-search task: further evidence. *Cognitive Development*, 4, 345-367.

Baillargeon, R. & Graber, M. (1987) Where is the rabbit? 5.5-month-old infants' representation of the height of a hidden object. *Cognitive Development*, 2, 375-392.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985) Object permanence in 5-month-old infants. *Cognition*, 20, 191-208.

Baldwin, D. A., Markman, E. M., & Melartin, R. L. (1993) Infants' ability to draw inferences about nonobvious object properties: evidence from exploratory play. *Child Development, 64,* 711-728.

Bower, T. G. (1974) *Development in infancy.* San Francisco: W. H. Freeman.

Carey, S., Uller, M. C., Huntley-Fenner, G. & Klatt, L. (1994) The representations supporting infant addition. Poster presented at the 9th International Conference on Infant Studies. Paris, France, June 2-5, 1994.

Cohen, L.B. & Younger, B.A. (1983) Perceptual categorization in the infant. In E.K. Scholnick (ed.), *New trends in conceptual representation,* 197-200. Hillside, N.J.: Erlbaum.

Columbo, J., Mitchell, D.W., & Horowitz, F.D. (1988) Infant visual attention in the paired-comparison paradigm: test-retest and attention-performance relations. *Child Development,* 59, 1198-1210.

Eimas, P. & Quinn, P. (1994) Studies on the formation of perceptually-based basic-level categories in young infants. *Child Development,* 65, 903-917.

Fodor, J. A. (1983) *The modularity of mind.* Cambridge, MA: MIT Press.

Frege, G. (1884/1959) *The foundations of arithmetic.* Oxford: Basil Blackwell.

Geach, P. (1957) *Mental acts.* London: Routledge & Kegan Paul.

Geach, P. (1962) *Reference and generality.* Cornell University Press.

Gratch, G. (1982) Responses to hidden person and things by 5-, 9-, and 16-month-old infants in a visual tracking situation. *Developmental Psychology*, Vol. 18, No. 2, 232-237.

Gupta, A. (1980) *The logic of common nouns.* New Haven: Yale University Press.

Hirsch, E. (1992) *The concept of identity.* Oxford University Press, New York.

Hall, D. G. (1993) Basic-level individuals. *Cognition*, 48, 199-221.

Hofsten, C. von & Spelke, E. S. (1985) Object perception and object-directed reaching in infancy. *Journal of Experimental Psychology: General*, 114, 198-212.

Huntley-Fenner, G. N. & Carey, S. (1995) Individuation of objects and non-solid substances: A pattern of success (objects) and failure (non-solid substances). Invited poster presented at the Biennial Meeting of the Society for Research in Child Development, Indianapolis, IN.

Huttenlocher, J. (1974) The origin of language comprehension. In R. L. Solso (ed.), *New directions in the study of language.* Cambridge, Mass., MIT Press.

Jackendoff, R. (1983) *Semantics and Cognition.* MIT Press, MA: Cambridge.

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, M. (1991) Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, 40, 1-19.

Kahneman, D. & Treisman, A. (1984) Changing view of attention and automaticity. In R. Parasuraman and D. A. Davies (eds.), *Varieties of Attention*. New York: Academic Press.

Kahneman, D., Treisman, A., & Gibbs, B. (1992) The reviewing of object files: object-specific integration of information. *Cognitive Psychology*, 24, 175-219.

Kellman, P. (1984) Perception of three-dimensional form in infancy. *Perception and Psychophysics*, 36, 353-358.

Kellman, P. (1993) Kinematic foundations of infant visual perception. In C. Granrud (ed.), *Visual perception and cognition and infancy*. Lawrence Erlbaum: Hillsdale, NJ.

Kellman, P. & Spelke, E. S. (1983) Perception of partly occluded objects in infancy. *Cognitive Psychology*, 15, 483-524.

Kellman, P., Spelke, E. S., & Short, K. R. (1986) Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development*, 57, 72-76.

Koffka, K. (1935) *Principles of Gestalt Psychology.* New York: Harcourt, Brace, & World.

Kohler, W. (1947) Gestalt psychology. New York: Liveright Publishing Corporation.

La Palme Reyes, M., Macnamara, J., Reyes, G. E., & Zolfaghari, H. (1994) Proper names and how they are learned. *Memory,* 1 (4), 433-455.

La Palme Reyes, M., Macnamara, J. & Reyes, G. (in press) A category-theoretic approach to Aristotle's term logic, with special reference to syllogisms. In R.S.Cohen & M.Marion (eds.), *Quebec studies in the philosophy of science.*

La Palme Reyes, M. (1994) Referential structure of fictional texts. In Macnamara & Reyes (eds.), *The logical foundations of cognition.* Oxford University Press, Oxford, England.

La Palme Reyes, M., Macnamara, J. & Reyes, G.E. (1994) A category-theoretic approach to Aristotle's term logic, with special reference to syllogisms. In Cohen & Marion (eds.), *Quebec studies in the philosophy of science.*

LeCompte, G., & Gratch, G. (1972) Violation of a rule as a method of diagnosing infants' levels of object concept. *Child Development,* 43, 385-396.

Legerstee, M., Pomerleau, A., Malcuit, G., & Feider, H. (1987) The development of infants' responses to people and a doll: Implications for research in communication. *Infant Behavior and Development,* 10, 81-95.

Legerstee, M. (1991) The role of person and object in eliciting early imitation. *Journal of Experimental Child Psychology*, 51, 423-433.

Leslie, A. (1994) ToMM, ToBy, and agency: core architecture and domain specificity. In Hirschfeld & Gelman (Eds.), *Mapping the mind: domain specificity in cognition and culture.* Cambridge University Press.

Leslie, A.M. & Keeble, S. (1987) Do six-month-old infants perceive causality? *Cognition*, 25, 265-288.

Macnamara, J. (1987) *A border dispute: the place of logic in psychology.* MIT Press: Cambridge, MA.

Macnamara, J. & Reyes, G.E. (1994) *The logical foundations of cognition.* Oxford University Press, Oxford, England.

Macnamara, J., Reyes, G. & La Palme Reyes, M. (1994) Reference, kinds, & predicates. In Macnamara & Reyes (eds.), *The logical foundations of cognition*. Oxford University Press, Oxford, England.

Mandler, J. (1992) How to build a baby II: Conceptual primitives. *Psychological Review*, Vol. 99, No. 4, 587-604.

Mandler, J. M. & Bauer, P. J. (1988) The cradle of categorization: Is the basic level basic? *Cognitive Development*, 3, 247-264.

Mandler, J., Bauer, P. & McDonough, E. (1991) Separating the sheep from the goats: Differentiating global categories. *Cognitive Psychology*, 23, 263-298.

Marr, D. (1982) *Vision*. Freedman: New York.

Markman, E. (1989) Categorization and naming in children. Cambridge, MA: MIT Press.

Meicler, M. & Gratch, G. (1980) Do 5-month-olds show object conception in Piaget's sense? *Infant Behavior and Development*, 3, 265-282.

Meltzoff, A. N. (1988) Infant imitation and memory: Nine-month-olds in immediate and deferred tests. *Child Development*, 59, 219-225.

Meltzoff, A. N. & Moore, M.K. (1992) Early imitation within a functional framework: the importance of person identity, movement, and development. *Infant Behavior and Development*, 15, 479-505.

Muller, A., & Aslin, R. (1978) Visual tracking as an index of the object concept. *Infant Behavior and Development*, 1, 309-319.

Needham, A. & Baillargeon, R. (1995) Object segregation in 8-month-old infants. Manuscript under review.

Oakes, L. M., Madole, K. & Cohen, L. B. (1991) Infants' object examining: Habituation and categorization. *Cognitive Development*, 6, 377-392.

Oviatt, S. (1980) The emerging ability to comprehend language: An experimental approach. *Child Development*, 51, 97-106.

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

Pinker, S. (1984) *Language learnability and language development.* Cambridge, MA: Harvard University Press.

Quine, W.V. (1960) *Word and object.* MIT Press: Cambridge, MA.

Quinn, P. C. & Eimas, P. (1993) Evidence for representations of perceptually similar natural categories by 3- and 4-month-old infants. *Perception*, 22(4), 463-475.

Roberts, K. & Horowitz, F. D. (1986) Basic level categorization in seven- and nine-month-old infants. *Journal of Child Language*, 13, 191-208.

Schmidt, H., Spelke, E.S., & LaMorte, V. (1986) The development of Gestalt perception in infancy. Presented at the Fifth International Conference on Infant Studies, Los Angeles, CA.

Soja, N., Carey, S., & Spelke, E. (1991) Ontological categories guide inductions of word meaning: Object terms and substance terms. *Cognition*, 38, 179-211.

Spelke, E. S. (1990) Principles of object perception. *Cognitive Science*, 14, 29-56.

Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992) Origins of knowledge. *Psychological Review*, Vol. 99, No. 4, 605-632.

Spelke, E. S., Breinlinger, K., Jacobson, K., & Phillips, A. (1993) Gestalt relations and object perception: a developmental study. *Perception*, 22, 1483-1501.

Spelke, E. S., Hofsten, C. von, & Kestenbaum, R. (1989) Object perception in infancy: interaction of spatial and kinetic information for object boundaries. *Developmental Psychology*, 25, No. 2, 185-196.

Spelke, E. S., Kestenbaum, R., Simons, D. & Wein, D. (1995) Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, Vol. 13, 113-142.

Streri, A. & Spelke, E. S. (1988) Haptic perception of objects in infancy. *Cognitive Psychology*, 20, 1-23.

Ternus, J. (1926/1938) Experimentelle Untersuchung ueber phaenomenale Identitaet. *Psychologische Forschung*, 1926, 7, 81-136. (Excerpts translated in W.D. Ellis (ed.), *A source book of Gestalt psychology*. London: Routledge Kegan Paul, 1938).

Wiggins, D. (1967) *Identity and spatio-temporal continuity*. Oxford: Basil Blackwell.

Wiggins, D. (1980) *Sameness and substance*. Oxford: Basil Blackwell.

Woodward, A., Phillips, A., & Spelke, E. (1993) Infants' expectations about the motion of animate versus inanimate objects. Poster presented at the Cognitive Science Society, Boulder, CO.

Wynn, K. (1992) Addition and subtraction by human infants. *Nature*, 358, 749-750.

Xu, F. & Carey, S. (in press) Infants' metaphysics: the case of numerical identity. *Cognitive Psychology*.

Xu, F., Carey, S., Raphaelidis, K., & Ginzbursky, A. (1995) Twelve-month-olds have the conceptual resources to support the acquisition of count nouns. *Proceedings of the 26th Stanford Child Language Research Forum*.

Xu, F. & Welch, J. (1995) Infants' ability to use object kind information in object individuation. Poster presented at the Biennial meeting of the Society for Research in Child Development, Indianapolis, IN.