

The *object : substance :: event : process* analogy

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Abstract. Beginning at least with Bach (1986), semanticists have suggested that the objects/events and substances/processes that nouns and verbs apply to are strongly parallel. We investigate whether these parallels can be understood to reflect a shared representational format in cognition, which in turn underlies aspects of the intuitive metaphysics of these categories. We hypothesized that a way of counting (*atomicity*) is necessary for object and event representations, unlike substance or process representations. Atomicity is strongly implied by plural language (*some gorps*, for novel *gorp*) but not mass language (*some gorp*). We investigate the language-perception interface across these domains using minimally different images and animations designed to encourage atomicity ('natural' spatial and temporal breaks), versus those that should not ('unnatural' breaks). Testing preference for matching such stimuli with mass or count syntax, our results support Bach's analogy in perception, and highlight the formal role of atomicity in object and event representation.

Keywords: semantics, philosophy of language and mind, object perception, event perception

1 Introduction

Linguists say that sentences are about events. Philosophers debate the metaphysics of event identity. Cognitive scientists posit event concepts to explain how creatures like us represent and reason about the world, and developmental psychologists ask how we come to have those concepts. But, do we mean the same thing by 'event' (Casati and Varzi 2008; cf. Goldman 2007)? Our project aims to resolve this question, in part, by studying the relationship between event semantics and event representations in the psychologist's sense. Broadly, it explores the thesis that the semantic structure of event quantification, originally introduced into the literature with a metaphysical interpretation (Davidson 1967), reveals properties of how the mind structures its experience of the world.

We investigate how language and representation relate in the event domain by following the lead of other semanticists and psychologists in analogizing to the object domain. Semantically, the referential properties of mass nouns like *water*, count nouns like *cup*, and plural noun phrases like *cups* are identifiable by demonstrating different combinations of cumulative, divisive, atomic, or plural reference (for early discussion, see Quine 1960, Cheng 1973, Cartwright 1975, Massey 1976, Burge 1977, Bunt 1979, 1985, Link 1983, Krifka 1989). Often, these combinations are understood to reflect real-world ontology: nouns that refer like *water* apply to substances, while *cup* applies to objects, and *cups* to pluralities of objects (Parsons 1979, Link 1983, Champollion 2010, among many others). Observing seemingly parallel referential properties in the verbal domain (Taylor 1977, Bach 1986), many have adopted a parallel theory: verb phrases like *sleep* apply to processes or activities, while 'once-only' *die* applies to events, and *jump* (*again and again*) applies to pluralities of events. We aim to understand these properties in representational, rather than strict ontological terms.

We explore the parallel between events and objects by drawing on an analogy first formalized by Bach (1986): Events, like objects (Link 1983), are 'atomic', and this property differentiates both objects and events from substances and processes. Our strategy for examining this analogy in cognition is to investigate whether a factor that affects object categorization in novel images (namely, 'naturalness' or 'non-arbitrariness' of shape) has a similar effect on event categorization in novel animations. Our experiments test whether people prefer novel count nouns to refer both to non-arbitrarily-shaped objects and to events that occur along non-arbitrarily-shaped paths. Likewise, they test whether people prefer novel mass nouns to refer both to arbitrarily-shaped objects and to events that occur along arbitrarily-shaped paths. Positive findings would suggest that people individuate events in ways that draw on some of the same representational strategies they use for ordinary objects.

1.1 Representations of objects and events

A great deal is known about object and substance representation based on how cognitive abilities like tracking and quantity estimation are deployed across development, and some initial steps have been taken towards understanding event and process representation. In the object domain, we know that adults are able to track up to four things in an array if they move cohesively (Pylyshyn and Storm 1988, Pylyshyn 2001), but are unable to track similarly-shaped entities that 'pour' from one location to another (vanMarle and Scholl 2003). Similarly, 8-month-old infants are able to detect when two rigid, cohesive objects made of sand are replaced with one, but they fail to detect two poured piles of sand being replaced with one pile (Huntley-Fenner, Carey, and Solimando 2002). In the event domain, we know that infants can detect numerical differences between sets of jumping events (Wynn 1996, Sharon and Wynn 1998; cf. Wood and Spelke 2005), with the same developmental precision and limits as for comparing sets of objects (cf. Feigenson 2007). When segmenting scenes into meaningful units, we know that adults will segment line drawings and traversals of an object along a path similarly, providing suggestive evidence for a common import to features of spatial and temporal boundaries (Maguire, Brumberg, Ennis, and Shipley 2011).

The most direct evidence we have for a cognitive correspondence between the event and object domains has been found in studies on the mapping between linguistic form and conceptualization. For instance, adults preferred to describe a novel, regularly-shaped piece of material using count syntax (*There is a blicket*), but an irregularly-shaped piece using mass syntax (*There is blicket*; Prasada, Ferenz, and Haskell 2002). These differences in conceptualization have downstream effects for how sentences with *more* are understood: 3-year olds judged sentences with *more blick* (mass syntax) to be true based on a number comparison just in case *blick* clearly applied to solid objects, where *more blicks* (count syntax) was uniformly judged to be true by number, regardless of what counted as *blick* (Barner and Snedeker 2006; cf. Barner and Snedeker 2005). Paralleling this result in the event domain, adult participants judged the relevant dimension for *do more V-ing* (mass syntax) depending on whether V named an event or process category (*kick_V* led to number comparison, *dance_V* to temporal comparison) whereas *do more V-s* (count syntax) uniformly lead participants to compare by number (Barner, Wagner, and Snedeker 2008).

1.2 Overview

In this paper, we use semantic evidence as a basis for exploring commonalities in how we recognize and represent static and dynamic entities. A distinction between these subtypes of ‘eventualities’—i.e., the difference between processes and events—goes back at least to Vendler (1957), and its parallel effects to the distinction between objects and substances on the linguistic quantificational system goes back at least to Bach (1986). We review this evidence in §2. The crucial distinction on the two sides of the analogy that we emphasize—i.e., what distinguishes object from substance, on the one hand, and event from process, on the other—is whether an entity is conceived of as falling under a concept that provides non-arbitrary divisive reference, or atomicity. Non-divisiveness of an entity x falling under a concept C requires that it is not possible to arbitrarily divide up x so that its count under C is greater (cf. Koslicki 1997 on Frege’s criteria for counting). Arbitrarily dividing a cup does not produce two cups, and arbitrarily dividing a delivery does not produce two deliveries.

In §3, we use Bach’s analogy to extend Prasada et al’s (2002) cognitive distinction between non-arbitrary and arbitrary spatial division to the event domain, where we emphasize non-arbitrary and arbitrary temporal division, see Table 1. There, we establish the prediction that naturalness of temporal divisions should lead to event (atomic reference) as opposed to process categorization (non-atomic reference). This prediction is tested in two experiments, which we report in §4.

	SPATIAL			TEMPORAL			
	object	:	substance	::	event	:	process
Semantics	atomic	:	non-atomic	::	atomic	:	non-atomic
Categorization	non-arbitrary	:	arbitrary	::	non-arbitrary	:	arbitrary

Table 1: The title analogy

This work is important for our developing understanding of the relationship between research in formal semantics and that in cognitive science more broadly, as well as for thinking about the structure of our semantic theories. That is, while the title analogy has traditionally been thought of in metaphysical terms, it can productively be viewed in cognitive terms if it generates predictions about how people represent and reason about the world. Such would be a substantial departure from standard practice in formal semantics, however.¹

¹ Bach (1986:15), for his part, cautions against the metaphysical construal of his analogy: “It is not part of linguistics to decide whether all matter is atomic or all happenings are reducible to little granules of process”, questions that he calls, in any case, “basically incoherent”. More likely, the analogy reflects “an artifact of our language or conceptualizations of the world”; even so, he cautions against linguists pursuing the cognitive construal, as “probably here too our strictly semantic theories should remain silent.”

2 Language

Since at least Bach (1986), it is generally agreed that the morphosyntactic mass/count distinction in the nominal domain corresponds to the atelic/telic distinction in the verbal domain (see also Krifka 1989). Roughly, these distinctions reflect linguistic commitments about different *kinds of things* (e.g., Vendler 1957, Link 1983, Champollion 2010, Wellwood 2015). The crucial distinction that we consider comes down to whether a predicate refers atomically, to objects or events, or non-atomically, to substances or processes.² In this section, we review the sorts of linguistic evidence that support, on the one hand, a parallel semantics for object- and event-referring expressions, and on the other, for substance- and process-referring expressions. Following this, we link the semantic theory to cognition.

2.1 Objects and events

Objects and events seem to be very different sorts of entities. Indeed, common-sense distinguishes objects as things that exist, that can be weighed; while in contrast, events are things that happen, and that cannot be weighed, etc. These sorts of common-sense intuitions are borne out in sensibility judgments for simple sentences: an object-referring expression like *the cocktail* is comfortable in a construction expressing measurement of weight, (1a), while an event-referring expression like *the party* is not, (1b). Meanwhile, since events occur at particular times, we can say when they start, (2b), but we can't say this about objects, (2a).³

- (1) a. The cocktail weighed 2 pounds.
- b. ? The party weighed a ton.
- (2) a. ? The cocktail started at midnight.
- b. The party started at midnight.

Beyond this difference, there are many commonalities, primarily concerning individuation and countability. Individuation can be seen by the amenability of object- and event-referring expressions to distributive quantification using expressions like *each* and *every*: for instance, (3a) expresses a one-to-one pairing relationship between cocktails and shots (Boolos 1981). A similar pattern can be observed in the verbal domain: (3b) expresses a matching relation between events of Bill drinking, and of Bill getting ornery. (See Rothstein 1995 for extensive discussion of constructions like (3b), and arguments against treating phrases like *every time* as involving, e.g., quantification over times as opposed to events.)

² We do not consider states in this paper; our focus is on the first level distinction between the non-stative eventualities (cf. Bach 1986).

³ Notice that there are perfectly good thoughts that one might want to express by sentences like (1b) and (2a); a speaker might intend to say how much the combined weight of the partygoers was, (1b), or when they started drinking the cocktail, (2a). But these strings cannot carry such meanings.

- (3) a. Every cocktail you buy, you get a free shot.
b. Every time Bill drinks, he gets ornery.

Regarding countability, it helps to see where it fails. An object-referring noun like *ring* cannot appear bare in a nominal comparative, (4a), or at least not to mean something about how much gold there is in the ring, or how many rings there are. The latter thought is expressed using the plural form *rings*, (4b).⁴ Showing the parallel in the verbal domain is a little bit difficult in English, which lacks certain helpful aspectual morphology, but it can nonetheless be observed in how an eventive predicate like *cross the English Channel* must be interpreted in the verbal comparative: (5) has no stable interpretation in contexts where Ann and Bill each crossed the channel once, it can only be interpreted as comparing counts of pluralities of crossings. (Wellwood, Hacquard, and Pancheva 2012 suggest that the latter interpretation indicates the presence of a covert pluralizing operator.)

- (4) a. ? Ann has more ring than Bill does.
b. Ann has more rings than Bill does.
(5) Ann crossed the English Channel more than Bill did. [?SG, PL]

More direct evidence comes from distinguishing counting from measurement. Object- and event-referring expressions are of the right sort to combine with expressions that directly contribute counts of entities. So we can say that Ann has 17 toasters, (6a), but even if it's true that their combined weight adds up to 40 pounds, it's odd to talk about her toasters in that way, (6b). Similarly, it is easily said and could be true that Ann crossed the channel a number of times, (7a), but it's odd to talk about her crossings with an indication of how long she spent at them, (7b).

- (6) a. Ann has 17 toasters.
b. ? Ann has 40 pounds of toaster(s).
(7) a. Ann crossed the English Channel 5 times.
b. ? Ann crossed the English Channel for 40 hours.

Approaches primarily associated with Link (1983) model the referential and quantificational properties of nouns like *toaster* and their plural variants in terms of a notion of atomic reference: singular *toaster* applies to atomic objects, and plural *toasters* applies to pluralities whose minimal parts are atomic objects. Atomic entities are ones that cannot be divided arbitrarily and find more instances of the same type of entity. Bach (1986), considering analogous properties in the verbal domain, extends this picture: predicates like *cross the Channel* apply to atomic events, and under some conditions, can be understood to apply to pluralities of atomic events.

⁴ See Barner and Snedeker 2005 for experimental evidence that plural-marked nouns are uniformly compared by number in the comparative construction.

2.2 Substances and processes

Substances and processes differ from each other in much the way that objects and events do. Like objects, common sense distinguishes substances as things that exist and can be weighed; like events, processes are things that happen and cannot be weighed. So we can say how much *the stuff* weighs, (8a), but it is odd to say how much *the fun* weighs, (8b). And indeed, we can say when a process got underway, (9b), but we can't say this about substances, (9a).

- (8) a. The stuff weighed 2 pounds.
- b. ? The fun weighed 2000 pounds.
- (9) a. ? The stuff started at midnight.
- b. The fun started at midnight.

Unlike objects and events, though, substances and processes are not naturally individuated, and so they cannot easily be distributively quantified. Combined with distributive *every*, the result is odd: a substance term like *mud* in (10a) doesn't include the necessary information for how one should individuate the mud, such that each atom can be said to have been tested. An exactly parallel pattern can be observed in the verbal domain. With *every* in (10b), we are left grasping to determine what could be the individual units of sleep that fit uniquely within 5 minute temporal intervals.⁵

- (10) a. ? Ann tested every mud that Bill dug up.
- b. ? Ann slept every 5 minutes last night.

Both substance- and process-referring terms are comfortable bare in the comparative form and, there, they are not interpreted as comparing numbers of things. That is, if Ann and Bill each found large portions of rock, (11a) can be used to say that the amount of Ann's rock exceeded the amount of Bill's. Here, 'amount' can be understood either in terms of volume or weight. Similarly, if Ann and Bill each slept for some period of time, (11b) can be used to express that the duration of Ann's sleep was greater than that of Bill.

- (11) a. Ann found more rock than Bill did.
- b. Ann slept more than Bill did yesterday.

The data from comparatives fit in nicely with how substance- and process-referring expressions pattern with numerals: they are more comfortably measured than counted. So it is natural to combine *mud* with a unit term and a numeral, (12a), but it is odd to predicate the substance-referring term directly with a numeral, (12b): an expression like *mud* fails to support a conventional way of counting. Similarly, it is natural to combine a nominal or verbal process

⁵ Of course, coercive interpretations of such nouns and verbs are possible. See Gillon 2012 for extensive discussion of conversions in the nominal domain; we expect similar conversions to be possible in the verbal domain.

term with a measure phrase to express the duration of the process or activity, (13a), but it is difficult to count using such expressions, (13b).

- (12) a. 5 gallons of mud
- b. ? 5 mud(s)
- (13) a. 5 hours of sleep/sleep for 5 hours
- b. ? 5 sleeps/sleep 5 times

One way of capturing the parallel properties of substance- and process-referring terms in the tradition following Link and Bach is to posit that the entities they apply to are non-atomic (or, anti-atomic; see Gillon 2012). That is, substances and processes have no minimal parts, let alone atomic parts, and so cannot be appropriately counted.⁶ One of the contemporary criteria for having such reference is (arbitrary) *divisiveness*: it is conceptually possible to take a portion of the stuff and divide it arbitrarily and still come up with more portions of the stuff.⁷ In this way, substances and processes, and the terms that we use to refer to them, do not provide the right kinds of materials for non-arbitrary counting (see Koslicki's 1997 discussion of Frege's criteria).

2.3 Formal identity issues

So far, we have pointed to intuitive evidence for an ontological distinction between objects and substances, on the one hand, and between events and processes on the other. However, there are also logical reasons to subdivide the domains of existents and happenings. These are revealed in paradoxes that arise when we confront what appear to be everyday judgments about identity.

Link (1983) recalls a simple puzzle that illustrates why, at least for the purpose of linguistic theorizing, we should not identify objects and substances, even when it most seems that they are one and the same. The puzzle begins with the observation that there can be an object, *r*, which can be truthfully said to be new, (14a), while it can be comprised of a substance, *g*, which can be truthfully said to be old, (14b). At the same time, common sense suggests that there is an important relation between the ring and the gold—that there is just one thing there, (14c). And while common-sense intuition appears to agree with (14a-c), nonetheless from this there follows a contradiction, (14d).

- (14) Object and substance identity issues

- a. The ring is new. **new(*r*)**

⁶ Saying that substances and processes are non-atomic or anti-atomic is not to claim that *mass terms*, as distributionally defined, entail such denotations. 'Mass' is a grammatical category that includes nouns like *furniture*, which arguably denote in domains with atomic minimal parts.

⁷ See Zucchi and White 1996 in particular for a linguistically-based discussion of object terms that appear to have this property, too, and Bunt 1985 for defense of the idea that language is neutral with respect to the 'how far down' divisiveness need go.

- b. The gold is old. $\neg \text{new}(g)$
- c. The ring is the gold. $r = g$
- d. Therefore, the ring is old. $\therefore \neg \text{new}(r)$

But of course, (14c) can be denied, and the contradiction avoided, by following Leibniz's law: if two things have different properties, then those two things are not identical. Accordingly, Link follows Parsons (1979) in assuming that the relationship between r and g is one of 'material constitution', not identity. (For arguments concerning the relation between constitution and identity in metaphysics, see Rea 1997). We indicate the material constitution relation as ' \triangleright^m ' in (15), which is read ' r is materially constituted by g '. Substituting (15) for the putative identity statement in (14c) evades the unwanted inference: under this scheme, objects with property P may easily be comprised of substances that do not have property P .

$$(15) r \triangleright^m g$$

Another piece of evidence comes from comparatives. How we understand sentences with *more* depends importantly on what is compared, and what we understand to be compared depends in an important way on the description. For example, while (16a) can express a comparison of the volume or weight of two portions of gold, that same comparison cannot be expressed substituting *ring* for *gold*, (16b). In fact, comparisons with non-plural object terms often seem odd. Wellwood (2014, 2015) analyzes data like these as revealing that comparison in language depends in part on whether an expression refers atomically or not.

- (16) a. I have more gold than you do.
- b. \neq ? I have more ring than you do.

Since Davidson (1967), it has become relatively uncontroversial in linguistics to interpret sentences as existential statements about events. Davidson conceived of events as standing in a one-to-many relationship with their descriptions (though see discussion and references in Goldman 1970, 2007, Pietroski 2015 for challenges). However, Davidson (1985) acknowledged some problems for this idea coming from adverbs: it seems that one and the same happening could be fast under one description, but slow under another. In fact, we can use these same adverbials to suggest that the domains of events and processes are distinct, setting up an analogous puzzle to that raised by Link for the object and substance domains.

Observe that there can be an event of Ann's crossing the English Channel, c , which can truthfully be said to be slow, (17a). This event can be comprised of her swimming, s , which can truthfully be said to be fast, (17b). At the same time, common sense suggests that the crossing of the Channel just *is* the swimming—that there is just one event there, (17c). But while common sense seems to agree with (17a)-(17c), from these the contradiction in (17d) follows.

(17) Event and process identity issues

- a. Anne crossed the Channel slowly. $\neg \text{quickly}(c)$
- b. Anne swam quickly. $\text{quickly}(s)$

- c. Anne's crossing was her swimming. $c = s$
- d. Therefore, Anne crossed the Channel quickly. $\therefore \text{quickly}(c)$

This problem can be avoided by analogizing Link's solution to the domains of events and processes. The referents of *swim* and *cross the Channel* need not be identified, though they can stand in a constitution relation. Thus, we might write ' \triangleright^τ ' to indicate temporal constitution, so (18) is read, ' c is temporally constituted by s '. This move raises a number of questions of just what 'temporal constitution' is; yet, the analogous identity puzzles suggest an analogous solution: material constitution for physical entities, temporal constitution for temporal entities. Substituting (18) for the interpretation of the putative identity statement in (17c) avoids the inference to (17d).

(18) $c \triangleright^\tau s$

A parallel piece of evidence comes, again, from comparative sentences. Suppose Anne and Bill both swam the Channel once, but it took Anne longer to do it. This state of affairs can be truthfully described using (19a), where *more* takes on an interpretation like *longer*. This interpretation is not equivalent to (19b), which is in fact odd when talking about singular crossings. The analysis in Wellwood (2014, 2015) captures these data in a parallel fashion to how she captures the difference between (16a)-(16b): a comparative semantics is incompatible with non-plural, atomic reference.

- (19) a. Anne swam more than Bill did.
- b. $\neq?$ Anne crossed the Channel more than Bill did.

3 Cognition

The linguistic data suggest similarities between the realms of existents and happenings. Both realms divide into a domain of individuated entities and a domain of unindividuated ones. Individuated entities (whether spatial or temporal) can be distributively quantified, counted, and are compared by their number. Unindividuated entities (whether spatial or temporal) cannot easily be distributively quantified, are better measured than counted, and are not preferentially compared by number. Within both realms, a constitution relation holds between the individuated entities and their unindividuated counterparts: processes can make up events in something like the way that substances can make up objects. These parallels raise the possibility that people employ a common set of conceptual tools in thinking about these realms.

A further hint about object/event similarities—one that will be important to the experiments we report here—comes from perceptual research. Consider a closed line drawing, such as the flower-shaped form in Figure 1. When people have to segment such a form into parts, they tend to choose points of minimum negative curvature (i.e., sharpest curvature in concave regions), producing as parts the petal-like areas (rather than, say, the outer half and the inner half of the form; e.g., Hoffman and Singh 1997). Similarly, if they see an object traversing a path of the same (but invisible) flower shape, they tend to segment the traversal event at the same minimum points (Maguire et al. 2011). Event segments are typically more variably distributed than those of

the corresponding objects (perhaps because segmenting events demands memory for earlier portions of the trajectory), and they sometimes include maxima (i.e., sharpest curvature in convex regions) as well as minima. But the overall similarity of the segments suggests that people use similar strategies in deciding on the boundaries of objects and events. We are not suggesting that part-whole relations for objects and events are solely a function of minima in their shape. Functional considerations can sometimes suggest part-whole relations, despite lack of clear spatial or temporal boundaries. But cross-domain sensitivities to minima can be useful in exploring the organization of these domains.

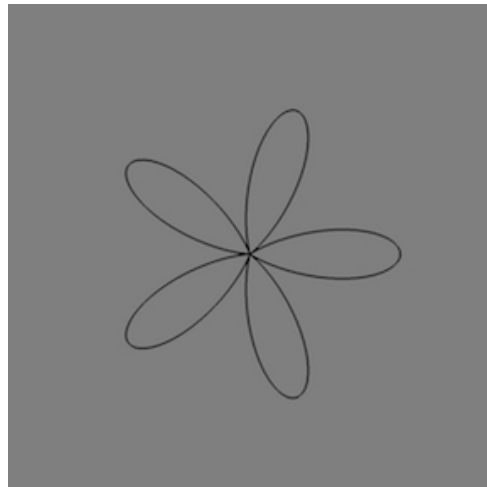


Figure 1: A simple representation of (a) a line-drawing, or (b) the path an object might traverse

Let's suppose, in line with these perceptual results, that segmenting objects or events at their negative minima produces more natural components than does segmenting at other points. The naturalness of these components may then highlight the parts as atomic, countable entities in their own right. If these assumptions are correct, we would expect people to be more likely to describe these natural components using count syntax (e.g., the plural morpheme) than components built from unnatural segments. For example, they should be more likely to use *some gorps* to label a spatial display of the petal-like parts than to use the same phrase to label a display of more arbitrary parts from the same flower. Similarly, they should be more likely to use *do some gleebs* to describe the activity of an object that traverses the outline of the flower, pausing at the minima, than to use the same phrase to describe a traversal that pauses at less natural points. The opposite predictions hold for the use of *some gorp* and *do some gleebing*: these phrases should seem more appropriate for components based on less natural breaks than for components based on more natural ones. The experiments in Section 4 assess these predictions.

We have framed these predictions in terms of the intuitive naturalness of the components, based on earlier results on object and event segmentation. But naturalness in this sense may be just one of a family of factors that determine atomicity and countability. For example, Prasada et al. (2002) found that people are more likely to apply a count noun than a mass noun to an irregularly shaped item if they had seen the same shape repeated on other items. This finding suggests that repetition conveys the idea that an item is non-arbitrarily packaged and, thus, a countable object. Repetition, regularity, functional significance, and natural boundaries all appear to belong to a set of features that call attention to the non-arbitrary (Prasada et al. 2002)

or shaped quality (Rips and Hespos 2015) of an item that potentially individuates it. Our goal here is not to document the role of all such factors but simply to show that one of them—natural divisions—can influence countability across the object and event domains.

It is important to note that research in cognitive psychology has considered parts of our controlling analogy, but has not yet addressed our central question. Wagner and Carey (2003) have shown that 3-5 year-old's counting of both objects and events is largely controlled by the spatio-temporal separation of the items. However, these children made some use of telicity in the case of events: Shown a movie of a girl eating an ice-cream cone in three bites, the children gave different counts to the question, "How many times was the ice-cream cone eaten?" than to "How many times does the girl eat?" Barner et al. (2008) provided evidence that punctual verbs (e.g., *jump*), which can occur over an interval only when repeated, lead to comparison by number when the term appears as a deverbal noun ("Who did more jumps?"). However, the relation that we aim to establish is either presupposed or not addressed in this work: parallels in what differentiates objects and substances, and what differentiates events and processes.

4 Language preference experiments

How do people prefer to describe an animation or image, given a choice of a novel mass or a novel count noun? We test the hypotheses we developed in the preceding section. If participants see an image divided at natural boundaries, they should be more likely to think of the components as atomic—and so a more appropriate target for count language—than if they see the same image divided at unnatural boundaries. Exactly the same should be true for animations: Natural divisions along a trajectory should be more likely to attract count syntax than should unnatural divisions.

4.1 Experiment 1

4.1.1 Predictions

We have said that objects and events crucially involve a notion of atomicity, whereas substance and process do not. Moreover, count syntax (i.e., addition of the plural morpheme on a noun) strongly implies atomicity, whereas mass syntax does not. Presented with animations or images that could, in principle, provide countable units—temporally-distinct happenings or spatially-distinct things—yet that differ in whether these units were natural or unnatural, the naturally-divided stimuli should be more likely to suggest object and event categories, unlike unnaturally-divided stimuli.

If participants are more likely to think of animations or images with natural divisions as indicating countable events or objects—and if their knowledge of language includes an understanding that count syntax implies such categories—then we make a clear prediction. Our participants should prefer sentences with a novel noun in count syntax to describe animations and images with naturally-divided stimuli than with unnaturally-divided stimuli. This pattern should hold regardless of whether the breaks are temporal (animations) or spatial (images).

Such a result would replicate Prasada, et al. (2002) for the object/substance distinction, and extend it to events/processes. However, it is possible that our cognitive interpretation of Bach's

analogy will not extend in this way. That is, while naturalness of spatial form could suggest object categorization, temporal pauses alone (whether natural or unnatural) could suggest event categorization. If so, we would predict different patterns for images and animations: naturally-divided images would be more likely to be paired with count syntax than unnaturally-divided images, but there would be no difference between naturally- and unnaturally-divided animations.

4.1.2 Participants

Participants were forty-seven Northwestern University undergraduates, recruited through the Department of Psychology subject pool, in accord with NU's Institutional Review Board (IRB) guidelines. They each received 1 lab credit for their participation.

4.1.3 Design

We designed a test manipulating DOMAIN (animations, images), BREAKS (natural, unnatural), and NUMBER (4, 5, 6, 7, 8, or 9). The factor DOMAIN manipulated whether the stimulus was an animation (event domain) or a still image (object domain). The factor BREAKS manipulated whether a spatial gap (images) or temporal gap (animations) was natural (occurring at regular intervals) or unnatural (occurring at random intervals). The factor NUMBER manipulated the number of breaks for a given image or animation, and was included in order to provide variability in the visual stimuli. Crossing these factors delivered 24 conditions. Each participant provided three judgments for each condition, in a design blocked by DOMAIN.

4.1.4 Materials (non-linguistic)

We created our stimuli in Matlab using the Psychophysics Toolbox 3.0.12 extensions (Brainard 1997; Pelli 1997; Kleiner, Brainard, and Pelli 2007). We first designed the animations, a sample of which is depicted statically in Figure 2. We programmed different paths that, were they visibly drawn, would look like a flower with 4, 5, 6, 7, 8, or 9 petals. An object, in our case a red star, could traverse that path and stop at different points along it. The path was the same regardless of whether the pauses were at the center of the 'flower' (natural breaks) or at random points along the path (unnatural breaks). Figure 2 represents 5-break unnaturally- and naturally-divided trials, with the path made visible and the star's pause points shown in each panel.

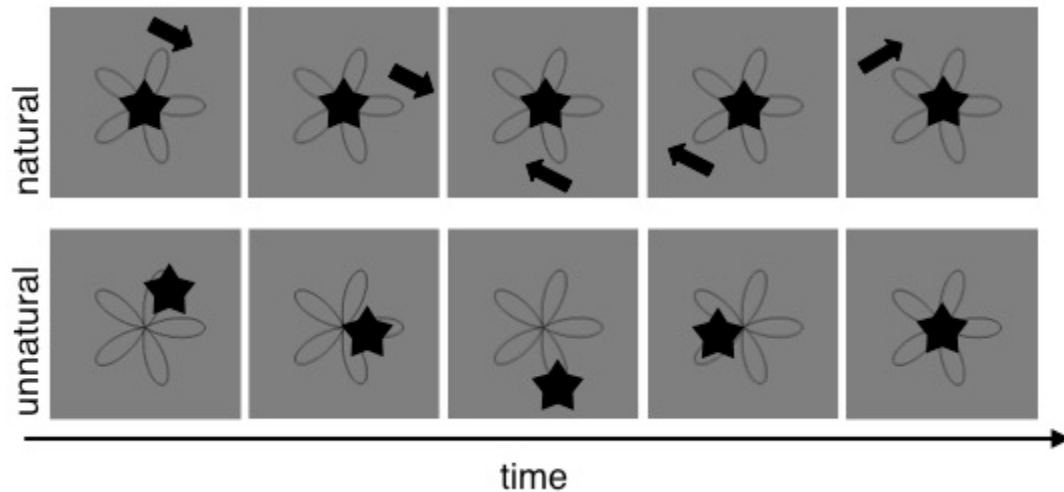


Figure 2: Two-dimensional renderings of sample animations from the 5-break conditions in Experiment 1. Study participants saw the star move along a path like that represented, but the path was not visibly drawn in the experiment. The star is represented at its stopping location at each temporal break.

We designed the images, samples of which are displayed in Figure 3, on the basis of the animations. Essentially, we instructed Matlab to draw lines corresponding to the pieces of the path that the star traversed in each type of animation, pull the pieces away from the center of the screen, and rotate them to a degree randomly selected between 0° and 360° . For the pictures based on the natural break animations, the result intuitively looked like a scattering of equally-shaped objects. For the pictures based on the unnatural break animations, the result looked like a scattering of randomly-shaped pieces of line-drawing.

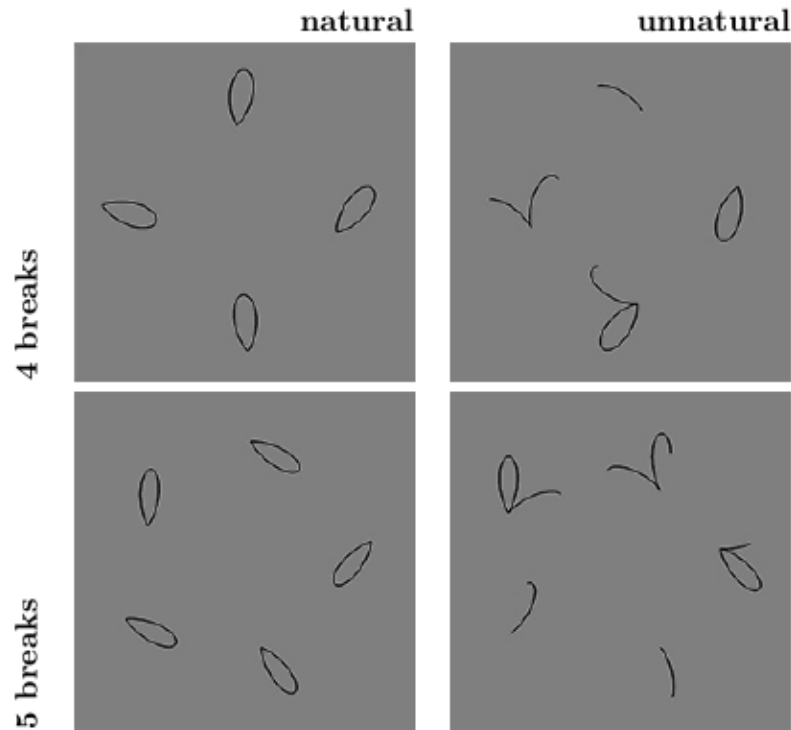


Figure 3: Sample images in Experiment 1

4.1.5 Materials (linguistic)

On each trial, we asked participants, “How would you prefer to describe that animation?” (animation conditions), or “How would you prefer to describe that image?” (image conditions). Two options were presented: a novel noun in count syntax, indicated by the presence of the plural morpheme and/or plural agreement on the copular verb, or mass syntax, indicated by the absence of the plural morpheme and/or singular agreement on the copular verb. Since every participant judged both animations and images, we changed the form of the novel noun between the conditions.

In the animation conditions, participants chose between (20a) and (20b). In the image conditions, they chose between (21a) and (21b).

(20) Language choices – animation conditions

- a. The star did some GLEEBS.
- b. The star did some GLEEBING.

(21) Language choices – image conditions.

- a. There were some GORPS.
- b. There was some GORP.

4.1.6 Procedure

The sequence of events during a trial appears in Figure 4. The beginning of each trial was signaled by a crosshair ('+') presented in the center of the screen for 1 second. Following that, an image or animation was displayed. The image was displayed for 3 seconds, and the animation was displayed for as long as it took the animation to complete its run (about 3 seconds on average). Immediately following, participants were asked to indicate how they'd prefer to describe the scene. They were instructed to press 'f' on the keyboard if they would prefer the count syntax—(20a) for the animations, (21a) for the images—or 'j' if they would prefer the mass syntax—(20b) for the animations, (21b) for the images. No attempt was made to draw participants' attention to the syntactic differences between the sentences, and no clues as to an interpretation for the nominal stems *gorp* or *gleeb* were otherwise offered.

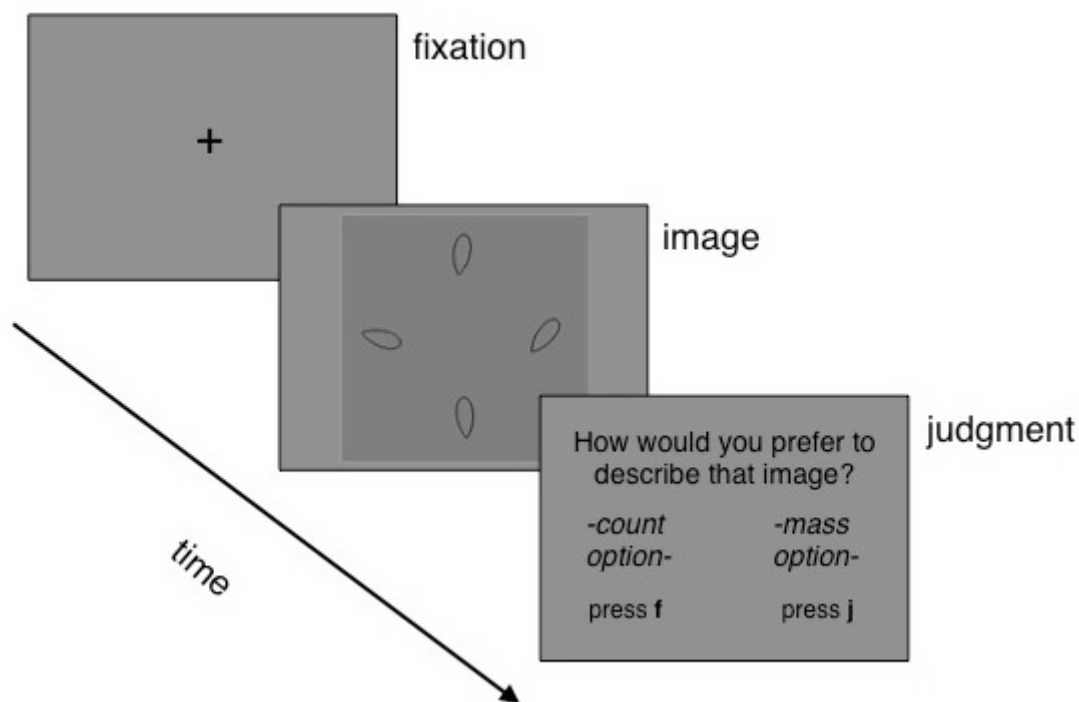


Figure 4: Trial structure of Experiment 1, demonstrated for a 4 naturally-divided image trial.

4.1.7 Statistical analysis

We report the results of logistic mixed effects regressions with maximal random effects structure, including random intercepts and slopes by subject (Barr, Levy, Scheepers, and Tily 2013). The choice of count syntax (vs. mass syntax, a binary variable) is the dependent measure. The χ^2 and p values that we report for main effects or interaction effects were derived from comparing the maximal model m against m minus the relevant factor or interaction term. All analyses were conducted using R's *lme4* package (Bates, Maechler, Bolker, and Walker 2014).

4.1.8 Results

Participants preferred count syntax to be paired with animations and images that contained natural temporal and spatial breaks. This result can be seen in Figure 5: the natural conditions received a higher proportion of count syntax than the unnatural conditions overall (proportion count syntax choices: unnatural .44, natural .74), $\beta = 2.96$, $SE = .66$, $\chi^2(1) = 17.3$, $p < .001$. Our participants treated naturalness of form as an important factor in choosing count syntax, as predicted by our controlling analogy; mere temporal pauses were not enough to see a stream of activity as consisting of separate events.

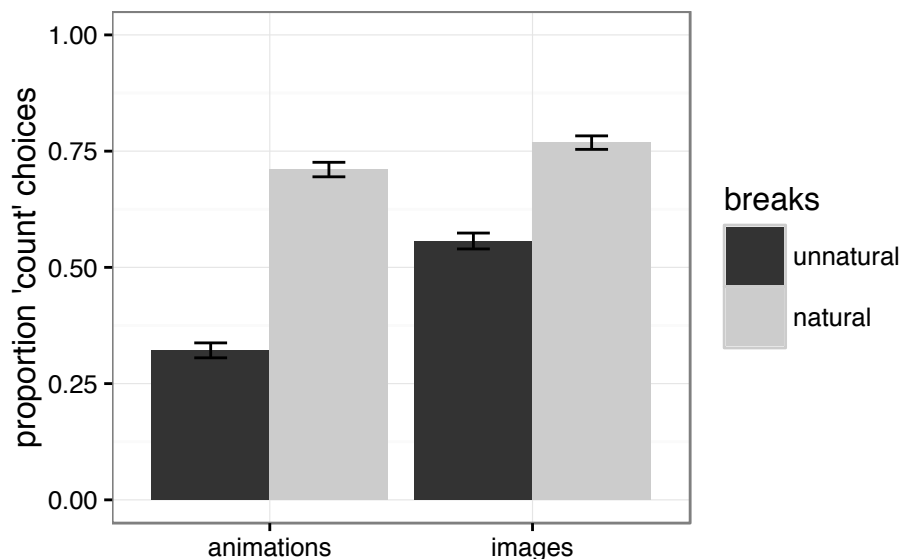


Figure 5: Results for Experiment 1

Participants also chose count syntax less in the animation conditions than in the image conditions (animations .52, images .66), $\beta = 1.66$, $SE = .58$, $\chi^2(1) = 7.8$, $p < .01$. While we did not predict this effect, it is not necessarily surprising. It could be that the spatial distance between the pieces in the image conditions increased the perception of countability relative to the connected path in the animation conditions. We test this possibility in Experiment 2. However, we found no interaction between DOMAIN and BREAKS, $\chi^2(1) < 1$. Naturalness of shape (whether spatial or temporal) influences categorization in the same way, in line with our controlling analogy.

The number of segments (4 – 9) in the image or animation had no effect on choice of count syntax, $\chi^2(1) < 1$. There was little difference in the proportion of count syntax chosen for the images and animations with the smallest number of breaks, and for the images and animations with the largest number of breaks (4 breaks .59, 9 breaks .6)—participants were not more likely to view *more things* as more suggestive of plural morphology, for example.

There was no interaction between BREAKS and NUMBER, $\chi^2(1) < 1$. But we did find an interaction between DOMAIN and NUMBER ($\beta = .77$, $SE = .38$, $\chi^2(1) = 4.1$, $p = .04$), wherein the proportion of ‘count’ choices increases slightly with the number of breaks for naturally-divided animations and unnaturally-divided images, but does not increase for unnaturally-divided

animations or naturally-divided images. Additionally, we found a three-way interaction of DOMAIN and BREAKS with NUMBER ($\beta = 2.14$, $SE = .76$, $\chi^2(1) = 7.4$, $p < .01$). The latter two effects do not concern the predictions of interest, and so we will not discuss them further.⁸

4.1.9 Discussion

This experiment assessed whether animations or images differing in whether their ‘parts’ were natural or unnatural would impact the selection of count syntax (*some gorps/do some gleebs*) versus mass syntax (*some gorp/do some gleeing*). We hypothesized that segmenting a line-drawing into natural pieces, and interrupting the traversal of an object at natural points along a path, would be more likely to lead participants to think of those pieces as instances of the categories ‘object’ or ‘event’. Categorizing their experience in this way would, in turn, lead to demonstrating a stronger preference for count syntax, as compared to categorization of minimally-different line-drawings and traversals that were segmented at unnatural points.

This prediction was born out in our experiment: participants were significantly more likely to select the count syntax options when the stimuli were broken along natural as opposed to unnatural joints, regardless of domain. This result supports the analogy between objects and events in perception, and for a link between language understanding and categorization in relation to these perceptual features. According to the semantic theory, entities falling under a plural noun like *gorps* must be atomic, and hence countable; atomicity, in the present case, was supported by naturalness of shape, whether for objects or events.

While it happened that our participants were more likely to prefer count syntax in our image conditions than in our animation conditions overall, this could have been due to special features of our displays: a larger spatial distance separated the components of the images than the components of the animations. Moreover, it is possible that this same feature—having the star pause in the center of the screen—might have independently influenced our naturally-divided animation conditions. We test these possibilities next.

4.2 Experiment 2

In this experiment, we modified the animations from Experiment 1 so that the moving object’s path is more closely aligned with the line drawings in the images.

⁸ Additionally, these effects did not reappear in Experiment 2, as we soon discuss.

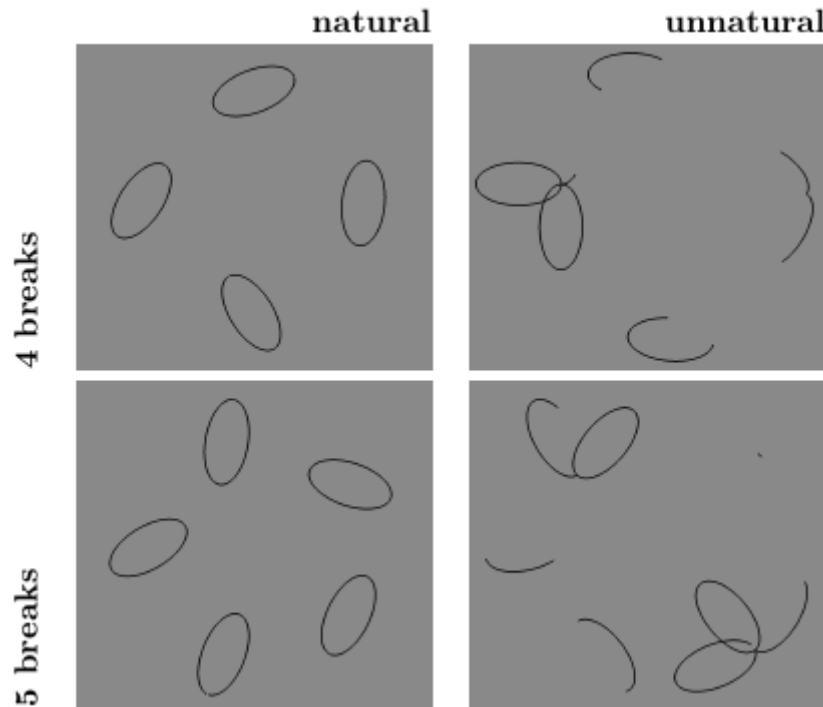


Figure 6: Sample images in Experiment 2

4.2.1 Predictions

It is possible that the parallelism in the results we found in the animations in Experiment 1 could have arisen due to a confound: the natural temporal divisions corresponded absolutely with another salient feature of the scene, the center of the screen. In this experiment, we divorced these two properties in the animations: the paths along which the star moved were spatially-separated, rather than centrally aligned. In line with our controlling analogy, we expected that this effect would not change the overall similarity of results between the animation and image conditions.

This same manipulation addressed a different concern. We observed in Experiment 1 that the proportion of count syntax chosen for the images was higher than for the animations. One reason for this could have been that the spatial divisions in the image conditions more strongly highlighted individuated units, which could have boosted count syntax choices for the images. By spatially-separating the events in Experiment 2 we expected that this would lead to a boost in choices of count syntax for the animation conditions.

4.2.2 Participants

Twenty-one Northwestern University undergraduates participated, recruited by advertisements distributed on campus which were approved by the NU Institutional Review Board (IRB). Each participant received \$10 for 1 hour of participation. The present study took approximately 30 minutes, and the remaining subject time was used for other studies.

4.2.3 Methods

The design and linguistic materials for this study were identical to that of Experiment 1. We again manipulated DOMAIN (animations, images), BREAKS (natural, unnatural) and NUMBER (4, 5, 6, 7, 8, or 9) in a within-subjects design blocked by DOMAIN. Participants were asked to make a language preference judgment for each image and animation, where the linguistic materials were as in (20a) and (20b) above.

We made two changes to the non-linguistic materials in this study, one of which was material to our predictions, and another of which was not. The material change was that, in the animations conditions, rather than have the star move along a continuous path interrupted by temporal pauses, the star moved along paths occurring at separate locations on the screen. That is, the paths that the star traversed in this experiment were exactly like the spatially distributed paths of the naturally- or unnaturally-divided images (see Figure 6), with no intermediate traversals (i.e., the star appears to ‘jump’ from one path to another after a delay). Under these conditions, the temporal pauses in the natural conditions were not associated with a salient spatial location, i.e., the center of the screen. The second change was that different mathematical equations were used to generate the paths for both the images and animations. Where Experiment 1 used polar loops, ellipses were used in Experiment 2. Samples of the slightly different shapes can be seen for a sample of the image conditions in Figure 6.

4.2.4 Results

The results for Experiment 2 were qualitatively identical to those of Experiment 1: participants preferred count syntax to be paired with animations and images that contained natural breaks (Figure 7). The natural conditions received a higher proportion of count syntax than the unnatural conditions (unnatural .44, natural .76), $\beta = 2.63$, $SE = .78$, $\chi^2(1) = 9.47$, $p < .01$. These results are as predicted by our analogy, and support the idea that it is *naturalness* (and not something like the spatial location of the temporal pauses) that influences event categorization in our animations.

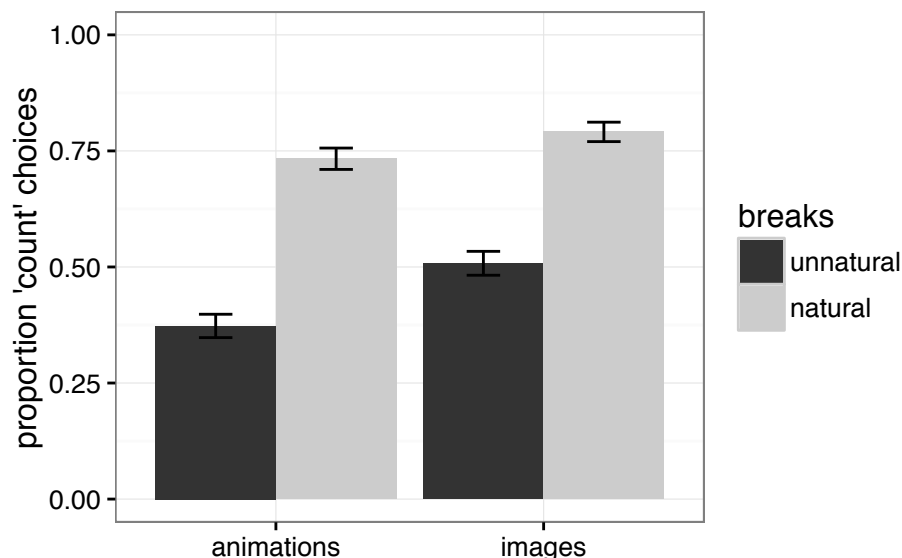


Figure 7: Results for Experiment 2.

Participants marginally chose count syntax more in the image conditions than in the animation conditions, a difference that was smaller overall than in Experiment 1 (images .65, animations .55), $\beta = 1.16$, $SE = .59$, $\chi^2(1) = 3.83$, $p = .05$. We predicted a lessening of the magnitude of difference here in light of spatially-separating the animations more like those of the images, which was borne out; however, the asymmetry was not entirely eliminated. In the discussion, we consider the possibility that the display time for the images is a further contributing factor. As in Experiment 1, we found no interaction between DOMAIN and BREAKS, $\chi^2 < 1$: naturalness of shape influenced categorization in the same way across domains, replicating the major result of Experiment 1.

As in the previous experiment, the number of segments (4 – 9) had no effect on the choice of count syntax, $\chi^2 < 1$. Participants' judgments of the appropriateness of count syntax did not increase along with the number of divisions on the screen. Additionally, there was no interaction between BREAKS and NUMBER, $\chi^2 < 1$, and the two unexpected interaction effects found in Experiment 1 were not observed in Experiment 2: we found no 2-way interaction between DOMAIN and NUMBER, $\chi^2 < 1$, nor any 3-way interaction between DOMAIN, BREAKS, and NUMBER, $\chi^2 < 1$. These results suggest that the corresponding effects in Experiment 1 were spurious.

4.2.5 Discussion

The results of Experiment 2 replicate those of Experiment 1. Both animations and images that are naturally-divided lead participants to a greater proportion of count syntax judgments with a novel noun. This pattern obtained regardless of whether the divisions are merely spatial, as in the image conditions in Experiments 1 and 2, temporal, as in the animation conditions in Experiment 1, or spatio-temporal, as in the animation conditions in Experiment 2. These results support the analogy between object and event representation, and for how language understanding connects with these representations.

One asymmetry between the animation and image conditions that persisted in Experiment 2 was that participants were somewhat more likely to prefer count syntax in the image conditions than in the animation conditions. While this asymmetry was lessened in Experiment 2 compared to Experiment 1, it did not disappear. In both of these studies, the images were displayed for 3 seconds, which is as long as it took the animations to complete on average. However, participants had the full 3 seconds to take in the image information, whereas they saw the animation gradually unfold within the same interval. Future research should determine whether the observed difference is neutralized when participants have less time to view the images.

5 General discussion

This paper investigated links between linguistic intuitions about sentences that seem to be ‘about’ objects and events, and perceptual intuitions about how simple scenes should be categorized. The linguistic data suggests two realms of representation, dividing happenings from existents. Each of these realms is further divided into the domains of objects and substances, and of events and processes. We hypothesized that the reflections of these categories in language reveal, however imperfectly, structures native to our cognition.

An important formal property shared between object and event representations is atomicity. We hypothesized, building on recent results in the cognitive psychology and perception literature, that this property could be suggested in a naturalness of shape, whether that shape was spatial or temporal. If a set of spatially- or temporally-discrete segments can be represented as pluralities of atomic entities, then they will meet the condition strongly implied by count syntax (*some gorps*). Acknowledging this strong implication is not to deny that mass language (*some gorp*), too, can be used to refer to pluralities; superordinate mass terms like *furniture* do this. Yet, count syntax is not merely neutral with respect to atomicity, but insists on it. And indeed, we found strong alignment between the naturalness of segments and the choice of count syntax in our two preference experiments.

One question raised by this work is whether we can say how the naturalness/non-naturalness of divisions guided decision-making behavior in our task: did atomic/non-arbitrary divisions encourage our participants towards count syntax, or away from mass syntax? We think the answer to such a question depends on two assumptions: (i) that speakers are aware (perhaps tacitly) that count syntax is more referentially restricted than mass syntax, and (ii) that participants tend to choose linguistic options that are more informative. With respect to (i), it is reasonable to assume that participants' implicit knowledge of the meaning of English morphosyntax includes the fact that count syntax requires atomicity, whereas mass syntax merely permits it (cf. Gillon 1992). Thus, if (ii) also holds, participants should choose the language that strongly implies atomic reference (count syntax) when presented with better candidates for that sort of reference (naturally-divided animations or images).

In future work, it will be interesting to probe the analogy between objects and events further. For instance, the present work suggests a second set of hypotheses. If natural spatial or temporal segments emphasize atomicity and countability, then the number of such segments should become a relevant dimension of comparison, driving judgments of similarity. For example, take two flower-like forms, such as the one in Figure 1, one with four ‘petals’ and the other with six.

Segmenting the forms into petal-shaped regions, the difference in number between such regions should become salient, decreasing the judged similarity between them. Our object-event analogy suggests that the same prediction should hold for traversals. Traversals of the same figures that pause at minima should highlight number, decreasing the similarity between the animations. By contrast, segmenting the same four-petaled form into four arbitrary (spatial or temporal) portions and the same six-petaled form into six arbitrary portions should not increase the salience of their number, and should not reduce similarity to the same extent.

It will also be important to conduct follow-up studies that control for precisely the factors influencing categorization in terms of objects and events as opposed to substances and processes. We have tested a notion of naturalness, wherein the divisions deliver common petal shapes (natural) versus arbitrary shapes (unnatural). However, mere non-arbitrariness could suffice (cf. Prasada et al. 2002). We are testing this possibility in a follow-up study, contrasting our current unnaturally-divided stimuli with non-arbitrarily divided stimuli, wherein the pauses (spatial or temporal) begin at a non-center point along the flower path—delivering shapes that are non-arbitrary but not natural. Extending Prasada et al. (2002) using our analogy, we expect that non-arbitrariness should bias toward count syntax about as strongly as naturalness did.

Finally, our discussion and results have implications for language acquisition research. We found that adults differentiated between naturally- and unnaturally-divided images and animations, preferring to label the naturally-divided scenes using count syntax, thereby implying atomic representation. Yet, children might not make the same distinctions as adults, at least at a certain age. For instance, Shipley and Shepperson (1990) found that young children are biased to label parts of an object using the plural noun for the object category (e.g., three pieces of a fork are likely to be labeled using *three forks*). Wagner and Carey (2003) found a similar bias when children were asked to count events: they tended to count interruptions of a goal-directed activity like *paint a flower* each as instances of painting a flower. It would be possible to test for this bias using materials like ours in an adaptation of a task by Barner and Snedeker (2004). Introducing children to naturally- vs unnaturally-divided animations and images and a novel expression *gleeb*, how would children understand sentences like *A gleebed more than B* or *There was more blue gleebed than red gleebed*?

Even beyond language acquisition, one might wonder about the origins of the commonalities we've found between objects and events. Recent studies suggest that even prelinguistic infants can make use of mappings between spatial dimensions of objects and temporal dimensions of events. For example, their memory for the length of an object is aided when the length is paired with a tone of a positively correlated duration (Srinivasan and Carey 2010). This finding raises the possibility of a similar pre-verbal mapping between the atomicity of objects and of events, one that we hope to explore in further research.

Our results reveal that people categorize aspects of their experience in object/substance and event/process terms, and that their categorizations have consequences for how they describe their experience. We have not addressed directly how these two faculties—conceptualization and language—connect with one another. On classical semantic approaches to a verb like *jump*, that verb expresses a property of individuals (i.e., the jumpers). On neo-Davidsonian approaches (Parsons 1990; Schein 1993; Pietroski 2005, a.o.), it expresses a property of events. If people natively divide their experience into distinct categories such as those that we've discussed, then

the task of explaining how semantic competence aligns with those categories will look very different on the two approaches. The neo-Davidsonian can claim a certain transparency in the mapping—object property terms relate to object concepts, just as event property terms relate to event concepts—while the classical view needs to say how an object property term comes to relate to an event concept.

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