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Boundedness Supports Children's Event Representations

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Natural languages distinguish between telic predicates that denote events leading to an inherent endpoint (e.g., *draw a balloon*) and atelic predicates that denote events with no inherent endpoint (e.g., *draw balloons*). Telicity distinctions in many languages are already partly available to 4–5-year-olds. Here, using exclusively nonlinguistic tasks and a sample of English-speaking children, we ask whether young learners use corresponding temporal notions to characterize event structure—that is, whether children represent events in cognition as *bounded* temporal entities with a specified endpoint or *unbounded* temporal units that could in principle extend indefinitely. We find that 4–5-year-old children in our sample compute boundedness during an event categorization task (Experiment 1) and distinguish event boundedness from event completion (Experiment 2). Furthermore, 4–5-year-olds in our sample evaluate interruptions at event endpoints versus midpoints differently—but only for events that are construed as bounded, presumably because in such construals, events truly culminate (Experiment 3). We conclude that young children represent events in terms of foundational and abstract temporal properties. These properties could support the acquisition of linguistic aspectual distinctions and further scaffold the way children conceptualize and process their dynamic experiences.

Public Significance Statement

The present study shows that 4–5-year-old children classify and interpret events in terms of abstract temporal structure (i.e., the way an event begins, develops, and ends). The sensitivity to event temporal profiles could support the acquisition of temporal distinctions in language and further scaffold the way children conceptualize and process their dynamic experience.

Keywords: boundedness, aspect, event cognition, telicity, goals

The world provides us with a continuous stream of experience. To make sense of it, we encode continuous input in terms of discrete units. These units are what we call "events," often defined as temporal segments that have "a beginning and an end" (Zacks & Swallow, 2007; Zacks & Tversky, 2001). Inspired by adult models of event segmentation (Magliano et al., 2001; Newtson et al., 1977; Zacks, 2004; Zacks et al., 2007), developmental research has shown that infants and young children use multiple cues to segment the continuous flow of action into discrete events (Baldwin et al., 2001; Hespos et al., 2009; Meyer et al., 2011; Pace et al., 2013; Saylor et al., 2007; Stahl et al., 2014; Y. Zheng et al., 2020).

A key finding from the literature on event cognition is that endpoints are critical event components for both children and adults. For instance, infants' perception of action is guided by whether the endpoint of action coincides with the achievement of a goal (Csibra, 2008; Csibra et al., 2003; Henrichs et al., 2014; Woodward, 1998, 1999). Relatedly, in both memory and language, both children and adults encode the goal of motion events (i.e., the physical endpoint of a motion, as in *A girl walked into the classroom*) more accurately compared to the source (*A girl walked from her home*; Lakusta et al., 2017; Lakusta & Landau, 2005, 2012; Papafragou, 2010; Regier & Zheng, 2007). More generally,

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in adults, event boundaries are privileged in memory and have a larger influence on the understanding and describing events compared to other time points (e.g., Boltz, 1995; Swallow et al., 2009; for a review, see Radvansky & Zacks, 2017).

Despite the importance of event endpoints for event cognition, what counts as an endpoint (and thus an event itself) is not straightforward. Currently, the most prominent event segmentation accounts in both adult and developmental studies offer a mechanism for chunking dynamic input from experience into discrete event units but do not address the representational content of each event unit (including what counts as an event endpoint). Here, we argue that the way language encodes event structure provides researchers with a novel, powerful framework for defining events and their endpoints and opens up new ways of understanding how young learners (and adults) construe the temporal profile of events.

Internal Structure of Events in Language

Verbs and other predicates can denote two types of events that have different internal temporal structures and come to an end in different ways (Bach, 1986; Dowty, 1979; Garey, 1957; Jackendoff, 1991; Smith, 1991; Vendler, 1957; see Filip, 2012 for an overview). *Telic* predicates (e.g., *A girl drew a balloon*) denote events that develop toward a "built-in terminal point" (Comrie, 1976), "climax" (Vendler, 1957), or "culmination" (Parsons, 1990). The endpoint of such events is inherent: it can be predicted from the outset and realized if the event is not interrupted (Mittwoch, 2013). In our example, the event of drawing a balloon ends when a picture of a balloon comes into being. By contrast, *atelic* predicates (e.g., *A girl drew balloons*) denote events that can terminate arbitrarily. The endpoint of such events is unspecified (e.g., the event described by *A girl drew balloons* could end at any moment). In this sense, telic predicates can be considered "atomic" or individuated (Bach, 1986), and atelic predicates unspecified with respect to atomicity or individuation.

Linguistically, telic and atelic predicates behave differently. Telic descriptions are congruent with delimited temporal phrases indicating that the inherent endpoint has been achieved within a certain amount of time (*A girl drew a balloon in half an hour*) but are incongruent with durative temporal phrases (*??A girl drew a balloon for half an hour*). The opposite holds for atelic descriptions (*A girl drew balloons for half an hour* is fine, but not *A girl drew balloons in half an hour*; Dowty, 1979; Smith, 1991).[1] Lexical, syntactic, and pragmatic factors contribute to the telicity profile of a predicate (Borer, 2005; Jackendoff, 1996; Kratzer, 2004), and even though the roles of these factors may vary, telicity is robustly present cross-linguistically (Bar-El et al., 2005; Botne, 2003; Filip, 2004; Friedrich & Gateva, 2017; Kardos, 2016; Singh, 1998; Soh & Kuo, 2005; Zhang, 2020).

Prior work with children with different native languages has revealed early sensitivity to telicity contrasts (e.g., van Hout, 2016; Wagner, 2006). Around the age of two, when children start to talk about their dynamic experience, they tend to use telic predicates for events that have reached their inherent endpoint (e.g., *fell*) or atelic predicates for events that are still ongoing (e.g., *dancing*), but rarely encode an ongoing event with a telic predicate (e.g., *falling*) or a terminated event with an atelic predicate (e.g., *danced*; French-speaking children: Labelle et al., 2002; Chinese-speaking children: Li & Bowerman, 1998; Japanese-speaking children: Shirai & Andersen, 1995). Furthermore, 3–5-year-olds give different answers to questions with different aspectual profiles. For instance, when seeing a video of a girl eating up a cookie in three bites and hearing a question including a telic predicate such as "How many times was the cookie eaten?" English-speaking children at Age 3 would count how many inherent endpoints had been achieved and answer "One"; if the question involved an atelic predicate such as "How many times did the girl eat?" children would count each cessation and answer "Three" (Wagner, 2006; Wagner & Carey, 2003; cf. Barner et al., 2008; Wellwood et al., 2018). Nevertheless, children do not fully acquire the way telicity is expressed in their language until school age (e.g., Gentner, 1978; Gropen et al., 1991; Hacohen, 2012; Hodgson, 2001; Jeschull, 2007; Liu, 2018; Ogiela, 2007; Penner et al., 2003; Stoicescu & Dressler, 2022; van Hout, 1998; for an overview, see van Hout, 2018).

Importantly, for present purposes, telicity is often assumed to rely on prelinguistic notions of event structure (e.g., Filip, 1999; Folli & Harley, 2006; Malaia, 2014). In support of this view, there is evidence that both adults and children interpret telicity as indicating different perspectives on events (Barner et al., 2008; Malaia et al., 2012; Strickland et al., 2015; van Hout, 2007, 2016, 2018; Wagner, 2006, 2012; Wagner & Carey, 2003; Wellwood et al., 2018). Below, we pursue the hypothesis that a cognitive counterpart of linguistic telicity is an organizing feature of event cognition.

Boundedness as a Formal Property of Event Cognition

We take the perspective that the internal temporal texture of events—whether events have inherent boundaries (beginnings and especially endpoints), a formal feature that we will call *boundedness*—shapes the way events are conceptualized in nonlinguistic cognition. The term is used as a cognitive counterpart of the linguistic notion of telicity. Despite its absence from current cognitive event frameworks, we take boundedness to be an ingrained and organizing property of cognitive event architecture, capturing the very unit of event representations. We view the cognitive ability to construe bounded and unbounded events as foundational for how children represent temporal entities in the world, just like the cognitive ability to construe objects and substances is foundational for how children represent spatial entities (see also Barner & Snedeker, 2006; Ji & Papafragou, 2022; Wagner & Carey, 2003; Wellwood et al., 2018; and especially Papafragou & Ji, 2023).

We take boundedness as a mental perspective on events, not an objective property of the sensory input: the same experience can often be construed in either bounded or unbounded terms, just as it can be described in either telic or atelic language (e.g., the same real-world episode can be construed as either *Mary drawing a flower* or *Mary drawing*; Wagner, 2009). We further assume that the human mind comes to conceptualize dynamic stimuli as bounded or unbounded via a process that involves both visual (Strickland et al., 2015; Wellwood et al., 2018) and conceptual cues (Filip, 2001; Kennedy & Levin, 2008; Mathis & Papafragou, 2022; Zacks & Swallow, 2007). Even though it is often possible to

[1] Telicity is distinct from goal-directedness, since the latter is neither necessary nor sufficient for a predicate to be telic. On the one hand, telic descriptions may refer to events that happen by accident (e.g., *Mom broke a dish when washing the tableware; Ariel kicked over a bottle while running across the street*). On the other hand, atelic descriptions may denote events that involve an intentional agent doing a goal-directed action (e.g., *Mom walked the dog in the dark; George brushed his teeth after dinner*).

flexibly construe the same dynamic input as either a bounded or an unbounded event, in many cases, observers are biased toward one construal over the other. For instance, people watching a football match tend to perceive moments when possession of the ball changes as event boundaries (in Huff et al., 2012). In other words, people are inclined to interpret such situations as bounded ("the player got the ball from the opponent") rather than unbounded events ("the players were handling the ball").

What factors lead viewers to form a bounded versus an unbounded event representation? For present purposes, we hypothesize that two types of visual cues are particularly important for boundedness construals (see Filip, 2004; Tenny, 1987 for similar observations from a linguistic perspective). A first cue relates to the nature of the action: some actions produce a distinct change of state in an object (e.g., close the door) while others do not produce a result stage (e.g., knock on the door). Object state changes have been shown to play a critical role in how events are represented (Hindy et al., 2012; Solomon et al., 2015; see also Kang et al., 2020; Misersky et al., 2021), attended to (Lee & Kaiser, 2021; Sakarias & Flecken, 2019) and remembered (Santin et al., 2021). Because the culmination of the change of state in an affected object offers a natural boundary to an event, events that involve a change of state are likely to be construed as bounded; conversely, events that do not appear to produce a visible change are likely to be construed as unbounded. A second cue relates to the quantization property of the affected object in an event—in other words, whether the affected entity is quantified (i.e., corresponds to one or a specific number of individuals) or not (a substance or an undifferentiated plurality). Because changes to an affected individual or set of individuals can provide a specific boundary for an event (e.g., the event of eating an apple/two apples ends when the apple(s) disappear), this type of affected entity can encourage bounded event construals; by contrast, changes to an affected substance or to an unspecified amount of objects can leave the event endpoint unspecified and encourage unbounded conceptualizations (cf. the event of eating cheese/crackers). A recent study showed that adults could form categories of bounded versus unbounded events on the basis of these two types of visual cues (Ji & Papafragou, 2020a).

In that study, participants were randomly assigned to either the Bounded or the Unbounded condition. During training, they watched paired videos of events that differed in a single feature that could bias their boundedness profile: that feature was either the action (dress vs. pat a teddy bear) or the affected object (blow a balloon vs. bubbles). Either the bounded or the unbounded member of each pair was surrounded by a red frame. At the test, participants could successfully indicate whether a new video (e.g., a girl peeling a banana) could get a red frame or not. Furthermore, when later asked about the meaning of the red frame, the vast majority of participants offered abstract conjectures about the internal profile of the events (calling examples of the bounded category "organized" or "neat" and those of the unbounded category "unorganized" or "messy"). Further experiments showed that adult viewers succeeded in the categorization task even when their use of language was blocked by a secondary linguistic task, removing the possibility that the categorization results were due to simple online encoding of the events in English (Ji & Papafragou, 2020a; see also Ji & Papafragou, 2020b, 2022). These results confirm the hypothesis that the abstract property of boundedness drives people's event representation.

The Present Study: Cognitive Representation of Boundedness in Children

Children have some awareness of event boundedness, as suggested by their developing knowledge about telicity. At present, however, little evidence exists about whether children draw the bounded–unbounded distinction when processing visual events *without* having to produce or understand event language. Furthermore, evidence of having acquired the aspectual distinctions of one's native language does not resolve the question of *how* children conceptualize boundedness as they process visual events (and whether that conceptualization itself could form the basis for the linguistic encoding of telicity). In addition, as mentioned already, languages differ in the ways they encode telicity (e.g., Botne, 2003; Filip, 2004). An intriguing possibility is that conceptualizations of event structure are similar across learners of different aspectual systems; this question requires nonlinguistic tasks to probe (see Sakarias & Flecken, 2019; van Hout, 2007, 2008). The present study builds on prior work on adult event cognition to investigate cognitive representations of event temporal structure in children. To our knowledge, this is the first study on how children process the internal temporal profile of events using exclusively nonlinguistic tasks.

Probing children's sensitivity to boundedness categories in nonlinguistic event cognition can offer a novel, more precise way of construing events and event boundaries and thereby enrich developmental theories of event cognition. Currently, the most prominent such theories focus on mechanisms of event segmentation (e.g., Baldwin et al., 2001; Hespos et al., 2009; Meyer et al., 2011; Saylor et al., 2007; Stahl et al., 2014; cf. Radvansky & Zacks, 2014; Zacks & Tversky, 2001) but do not address the representational content within event boundaries or the way segmented events are related to one another to form event types. These accounts were not designed to distinguish event representations that differ in terms of how an event may come to an end (e.g., an event of drawing a balloon culminates while an event of drawing balloons involves mere cessation). Investigating children's cognitive ability to distinguish bounded from unbounded event categories can advance our understanding of how children track, understand, and categorize dynamic input. A better understanding of children's representation of abstract event structure can also shed light on the cognitive prerequisites for the acquisition of lexical aspects (van Hout, 2007, 2016, 2018; Wagner, 2012). In Experiments 1 and 2, we ask whether 4–5-year-olds (who are still developing their linguistic knowledge of telicity; van Hout, 2016; Wagner, 2006; Wagner & Carey, 2003) can use properties of the action and the affected object to draw categories of bounded versus unbounded events.

Furthermore, understanding the role of boundedness in cognition can lead to novel predictions for how children process unfolding events. As alluded to earlier, the literature on event cognition typically assumes that event boundaries have a privileged status in memory and provide anchors for later learning and describing (Swallow et al., 2009). On this view, event endpoints, in particular, are critical for how events are represented by both children and adults (see He & Arunachalam, 2023; Lakusta & Landau, 2005, 2012; Papafragou, 2010; Regier & Zheng, 2007; Strickland & Keil, 2011). This literature has mostly drawn its examples from events with self-evident endings. If (un)boundedness is psychologically real and underlies children's conception of events, however, it

follows that event endpoints should be treated differently depending on the nature of event construal: endpoints should be privileged only for bounded construals (for which they represent an inherent boundary) but not for unbounded construals (for which the endpoint indicates simply the moment that the event stopped). On this account, the boundedness profile of an event is expected to have consequences for how the temporal stages of the event are apprehended. In Experiment 3, we examine whether sensitivity to boundedness affects how children process different temporal slices of an event.

Experiment 1

Experiment 1 explored whether 4–5-year-old children (and adults) represent events in terms of bounded versus unbounded categories using a categorization task similar to that in Ji and Papafragou (2020a). In each training trial, children were exposed to a pair of bounded and an unbounded event that differed minimally from one another; throughout training, videos of one event category (either bounded or unbounded) were marked by a star. Later, the children watched a series of new videos and had to decide whether each of those videos could get a star or not. Of interest was whether, during training, children could identify the target event category so as to later assign a star to new videos in that category (either bounded or unbounded).

As alluded to already, the same experience can be construed from both a bounded and an unbounded perspective, and it is the learner's mind that applies boundedness categories to streams of sensory information. Nevertheless, an event is not equally likely to be perceived as bounded or unbounded. As a first step, we focused here on events that—even though, in principle, multiply interpretable—were readily perceived by adult viewers as belonging to one or the other boundedness category. Our own stimuli were purposefully constructed to include properties of the action or the affected object that could promote either a bounded or an unbounded conceptualization. For ease of reference, we refer to our stimuli as either bounded or unbounded events.

Method

Transparency and Openness

In all of our experiments, we have reported how we determined our sample size, all data exclusions, all manipulations, and all measures, and we follow Journal Article Reporting Standards for Quantitative Research in Psychology (Appelbaum et al., 2018). This study's design and its analysis were not preregistered.

Participants

Forty 4–5-year-old children (age range: 4.1–5.3, mean age: 4.8, 19 female, 21 male) and 40 adults (age range: 18.4–21.5, mean age: 19.6, 19 female, 21 male) participated in the experiment. Both children and adults were native speakers of English. Children were recruited from the Early Learning Center and Laboratory Preschool, both of which were affiliated with the University of Delaware in Newark. These children were mostly from middle-class families and lived near the campus. They were identified as Caucasian (72.5%, $n = 29$), African American (17.5%, $n = 7$), or Asian (10%, $n = 4$). Adults were undergraduates at the University of Delaware and received course credit for participation. The adult sample was 77.5% Caucasian ($n = 31$), 10% African American ($n = 4$), 5% Asian ($n = 2$), and 7.5% unreported ($n = 3$). Data from an additional group of three children were collected but excluded: one child was distracted and did not finish the test; two children exhibited a response bias (they consistently assigned a star to the video stimuli throughout the test). Approval for testing these participants has been obtained from the University of Delaware institutional review board (Project title: The Interface Between Spatial Cognition and Language; institutional review board Protocol Number: 165481). Our sample size was decided based on the calculated power of Experiment 1 by Ji and Papafragou (2020a), which adopted the same design. The power analysis was based on the reported mixed-effects model (Ji & Papafragou, 2020a, p. 5) with Condition (Bounded vs. Unbounded) as the fixed predictor of interest, using the *simr* package in R (Green & MacLeod, 2016). The estimated effect size for Condition was −1.4, and the power of this predictor was 92%, suggesting that 80 participants (20 per condition for each age group) were adequate to achieve a power of 0.80 at $\alpha = .05$.

Stimuli

Sixteen pairs of videos featuring a girl doing an everyday action in a lab room were created (cf. also Ji & Papafragou, 2020a). All of the videos began with the girl picking up an object or tool and came to an end with the girl putting down the object or tool. Each pair of videos had the same duration (range: 5−13 s; $M = 7.6$ s) and was meant to illustrate a contrast between bounded/unbounded event construals (see Table 1). For half of the videos, paired events involved the same object(s) but differed in terms of the nature of the action performed on the object (Figure 1a and 1b): to encourage a bounded construal, one member of the pair included an action that caused a clear and temporally demarcated change of state in the object (e.g., roll up a towel, stack a deck of cards); to invite an unbounded construal, the counterpart event did not include such a change but involved an indefinite iteration of some motion (e.g., twist a towel, shuffle a deck of cards) that did not produce a result state. This set of videos involved a variety of objects, including a single individual (e.g., a towel), multiple objects (e.g., a deck of cards), or substances (e.g., yogurt, see Table 1). For the other half of the videos, paired events involved the same action (e.g., remove outermost peel or shell) but differed in terms of the nature of the affected object (Figure 1c and 1d): to encourage a bounded construal, one event involved a single object that was transformed by the action (e.g., peel a banana); to encourage an unbounded construal, its counterpart involved either an unspecified plurality of objects or a mass quantity that underwent a change of state (e.g., crack peanuts). The individual in bounded events could delimit the event boundaries (e.g., the event of peeling a banana begins with an intact banana and ends when the peel is separated from the fruit). By contrast, unbounded events typically included an unspecific quantity of small objects or substances (e.g., in the example of cracking peanuts, a number of peanuts spread on the desk) and thus lacked a specified endpoint.[2] We did not aim to compare the two sources (i.e., the nature of the action vs. the nature of the affected

[2] In reality, almost no event could last forever. The crucial property of unbounded events (in comparison with the bounded ones) lies in the lack of a well-defined or specified ending. In the case of cracking peanuts, one can stop their action at any moment and others would still describe what has happened as "cracking peanuts."

Table 1
Paired Video Stimuli Used in Experiment 1

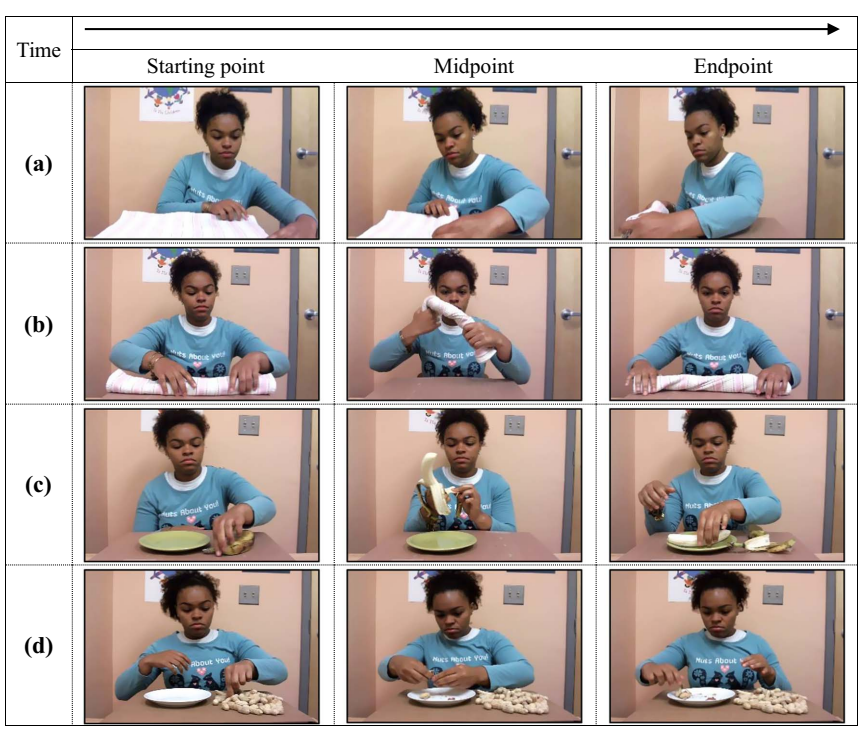
Phase	Boundedness source	No.	Bounded event	Unbounded event
Training	Nature of action	1	Fold up a handkerchief	Wave a handkerchief
		2	Put up one's hair	Scratch one's hair
		3	Stack a deck of cards	Shuffle a deck of cards
		4	Group pawns based on color	Mix pawns of two colors
	Nature of the affected object	5	Draw a balloon	Draw circles
		6	Tie a knot	Tie knots
		7	Eat a pretzel	Eat cheerios
		8	Flip a postcard	Flip pages
Testing	Nature of action	9	Dress a teddy bear	Pat a teddy bear
		10	Roll up a towel	Twist a towel
		11	Fill a glass with milk	Shake a bottle of milk
		12	Scoop up yogurt	Stir yogurt
	Nature of the affected object	13	Peel a banana	Crack peanuts
		14	Blow a balloon	Blow bubbles
		15	Tear a paper towel	Tear paper towels
		16	Paint a star	Paint stuff

Note. Each row depicts a pair of events. In the training phase, participants saw both events within a pair. In the testing phase, participants saw only one event from each pair.

object) in the present study, and thus, the two sets of videos were always intermixed in the experiments. Since whether an event has an inherent endpoint cannot be reduced to a single feature, our stimuli were not designed to be contrastive along just one dimension.

We conducted two norming studies to support the placement of the stimuli within the bounded versus the unbounded class. First, we conducted an event description task with 20 English monolingual adults (age range: 18.0–21.8, mean age: 19.3, 10 female, 10 male). Participants were asked to watch a subset of the video clips and describe what happened. For this norming task, the events in Table 1 were split into two lists, such that each list included only one member of each pair with boundedness and the source of boundedness

Figure 1
Examples of Paired Video Stimuli in Experiment 1: (a) Roll up a Towel (Bounded) Versus (b) Twist a Towel (Unbounded); and (c) Peel a Banana (Bounded) Versus (d) Crack Peanuts (Unbounded)



Note. See the online article for the color version of this figure.

counterbalanced. The participants were randomly assigned to one of the two lists. Their descriptions were coded for the verb phrase, which was composed of the verb (or verb particle) used to describe the action and the noun phrase used to describe the affected object(s). The verb phrases underwent linguistic *in some time* versus *for some time* test for telicity (see Dowty, 1979; Smith, 1991; Vendler, 1957; also the Introduction section) by four research assistants who were native English speakers (two assistants for each list). Overall, coders agreed with 90.6% of their telicity judgments. Discrepancies were resolved by the research assistants through discussion. As expected, stimuli of bounded events elicited telic verb phrases 93.8% of the time; those responses included change-of-state verbs or verb particles (e.g., *roll up a towel*) and quantified count noun phrases (e.g., *peel a banana*). Stimuli of unbounded events elicited atelic verb phrases 90.3% of the time; responses included verbs of activity (e.g., *twist a towel*) or unquantified noun phrases (bare plurals or mass nouns, e.g., *crack peanuts*). No significant difference was found between the two event classes in terms of whether they elicited the expected aspectual distinctions in the description task, $t(19) = 1.87$, $p = .077$. These results indicated that the preferred boundedness construals for our video stimuli aligned with the linguistic telicity distinction in English.

Second, we elicited judgment about the temporal structure of the video stimuli from a new group of 40 adults (see also Ji & Papafragou, 2020b). As in the linguistic norming study, the paired events in Table 1 were separated into two lists, and the participants were randomly assigned to one of the two lists. After watching each video, they answered the question, "Does it make sense to think of the action in the video as something with a beginning, midpoint, and specific endpoint?" The bounded stimuli received a *Yes* response 87.2% of the time, but their unbounded counterparts did so only 20.3% of the time, $t(39) = 20.05$, $p < .001$. These results showed that individual video stimuli were perceived as having properties that have been associated with either bounded or unbounded event structure.

Two additional norming studies were conducted to evaluate potential features of the stimuli that could possibly affect event categorization. First, we asked another group of 20 adults to rate the degree of intentionality for all videos on a scale from 1 (*totally unintentional*) to 7 (*intentional*; Ji & Papafragou, 2020a). There was no significant difference between scores for what we called bounded ($M = 5.61$) and unbounded events ($M = 5.48$), $t(19) = 1.14$, $p = .210$. Therefore, the agent's intention could not drive the distinction between bounded and unbounded stimuli.

Last, we assessed the degree of visual cohesion of the bounded versus unbounded class of events used in the training phase (see Table 1; Ji & Papafragou, 2020a). This was done to ensure that the instances of both event classes looked equally similar to each other such that the categorization of these instances would not be affected by visual similarity. We created a new stimulus set by putting together all possible pairwise combinations of the eight videos of bounded events and intermixing them with all possible pairwise combinations of the eight videos of unbounded events. We asked a different group of 20 adults to rate the degree of visual similarity for each pairwise combination on a scale from 1 (*least similar*) to 7 (*most similar*). The average rating for pairs of bounded events ($M = 2.38$) did not differ from those of unbounded events ($M = 2.52$), $t(19) = -1.43$, $p = .169$.

The video stimuli were arranged into two basic lists corresponding to the two phases of the experiment. For the initial training phase, we arranged eight pairs of events—four in which boundedness was due to the Action and four in which boundedness was due to the Affected Object into a pseudorandomized presentation list such that the two videos within a pair were played in immediate succession and appeared side by side on the screen (the order of bounded–unbounded events within pairs was counterbalanced within the list). For the later testing phase, we arranged another eight pairs of videos into two lists. Each list contained one video from each pair. We counterbalanced whether the event was bounded or unbounded and whether the source of boundedness was the action or the object across lists.

Procedure

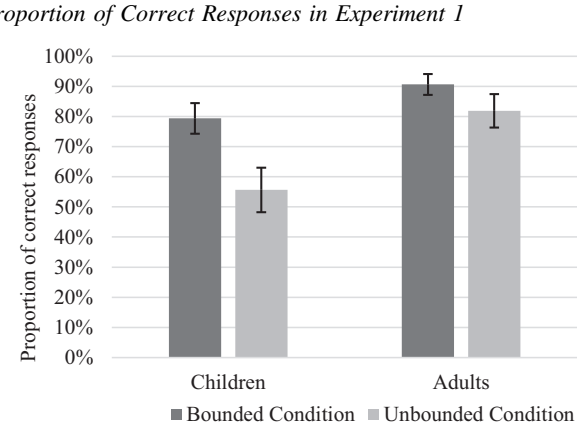
Participants were randomly assigned to one of two conditions. In the Bounded condition, a star appeared under the videos of bounded events but not under their unbounded counterparts in the training phase. In the Unbounded condition, the placement of the star was reversed.

In the training phase for both conditions, participants were invited to watch two videos appearing side by side on one screen each time. The video on the left played first, and the one on the right played second. After each video played, the last frame would remain on the screen. After both videos finished, a star appeared under one of the two videos, and the experimenter said, "Look! This video gets a star!" The participants' task was to figure out what kind of videos could get a star. In the testing phase, participants saw a set of new videos. Each time, a single video is played in the center of the screen. After watching the video, they were asked: "Could the video get a star or not?" Child responses were recorded by a research assistant. Adult participants recorded a *Yes/No* response on an answer sheet.

Results

Results from Experiment 1 are shown in Figure 2. The data from this experiment (and all subsequent experiments) were analyzed using multilevel mixed modeling with crossed intercepts for Subjects and Items (Baayen et al., 2008; Barr, 2008). All models

Figure 2
Proportion of Correct Responses in Experiment 1



Note. Error bars represent ±SEM. SEM = standard error of the mean.

were fitted using the *glmer* function of the *lme4* package in R (v4.2.1, R Core Team, 2021). The binary accuracy data were submitted to a logit model examining the fixed effects of Age Group (Children vs. Adults) and Condition (Bounded vs. Unbounded) and their interaction. All of the factors were coded using centered contrast (−0.5, 0.5). Random intercepts were provided for each Subject and each Item. We built up our logit model in a bottom-up fashion: including Age Group significantly improved the model fit, $\chi^2(1) = 29.75$, $p < .001$; similarly, Condition significantly contributed to the model fit, $\chi^2(1) = 25.46$, $p < .001$.[3] As shown in Table 2, the model revealed an effect of Age Group ($\beta = -1.10$, $z = -5.20$, $p < .001$): children ($M = 67.5\%$) were less successful in identifying the target event category than adults ($M = 86.3\%$). There was also a significant effect of Condition ($\beta = -0.94$, $z = -4.45$, $p < .001$): participants were better at forming the category of bounded events ($M = 85\%$) compared to unbounded events ($M = 68.8\%$). No significant interaction between Age Group and Condition was found ($p > .250$), suggesting similar patterns in both age groups. Unlike adults, the performance of children in the Unbounded Condition ($M = 55.6\%$) was not above chance levels, $t(19) = 1.506$, $p = .148$.

An additional set of analyses confirmed that the notion of (un)boundedness that we had in mind (as opposed to other possible constructs) was relevant to participants' categorization. Across the event items used in this experiment, we ran a linear regression to examine whether the proportion of responses that considered an event item as "having a beginning, midpoint and endpoint" (see our prior norming study) could predict the proportion of responses that categorized the item as bounded for both age groups. The norming responses about event structure could explain a significant proportion of the variance in the categorization responses of both adults, $R^2 = .913$, $F(1, 14) = 146.1$, $p < .0001$, and children, $R^2 = .841$, $F(1, 14) = 74.0$, $p < .0001$. Similarly, we ran a linear regression to examine whether the average rating for the degree of intentionality of an event item (as determined by our prior norming) would be a significant predictor for categorizing the event as bounded. The intentionality ratings failed to explain a significant portion of the variance in the categorization responses of both adults, $R^2 = .129$, $F(1, 14) = 2.07$, $p = .172$, and children, $R^2 = .025$, $F(1, 14) = .36$, $p = .558$.

Discussion

Experiment 1 led to two major findings. First, 4–5-year-old children are sensitive to the internal temporal profile of events: after watching a few contrastive examples, children could form a bounded event category and extend it to new examples. Furthermore, regression analyses show that children's categorization of the event items could be predicted by intuitions about which of these events could be considered to have a beginning, midpoint, and endpoint. These results comport with and extend recent work on event cognition with adults (Ji & Papafragou, 2020a; see also Sakarias & Flecken, 2019; Strickland et al., 2015). Since bounded and unbounded stimuli were equally visually similar to each other and equally intentional (at least according to adults in our norming studies), the ability to place events into classes cannot be reduced to either visual similarity or intentionality considerations.

Second, bounded events were treated differently from unbounded events: both age groups in our sample could identify the category of bounded events with greater ease compared to that of unbounded events, even though the difference between the two event categories was more pronounced in children's performance. In fact, unlike adults, 4–5-year-olds did not succeed in extracting the unboundedness category (i.e., the class of events that is characterized by the *lack of* an inherent endpoint). This result is reminiscent of a similar advantage for the bounded category in the adult data of Ji and Papafragou (2020a).

How can the asymmetry be explained? We propose that a well-defined endpoint acts as an anchor for individuating and comparing bounded events and helps form a generalization about the bounded category; in other words, the development toward a predictable endpoint in a bounded event structure is easier to track. By contrast, the *lack* of internal development in an unbounded event structure, together with a less predictable endpoint, makes it harder to track unbounded events. This account is in line with models arguing that significant changes in event features (i.e., moments of culmination within bounded events) are associated with increasing processing activity in the brain of event observers and help with event understanding (Swallow et al., 2009; Zacks et al., 2007). We revisit the bounded–unbounded difference in later sections.

Table 2
Fixed Effect Estimates for Multilevel Model of Identifying the Target Category in Experiment 1

Effect	Estimate	*SE*	*z* value
(Intercept)	1.34	0.11	12.64***
Age group (children vs. adults)	−1.10	0.21	−5.20***
Condition (bounded vs. unbounded)	−0.94	0.21	−4.45***
Age Group × Condition	−0.36	0.42	−0.85

Note. Formula in R: Accuracy ~ 1 + (1|Subject) + (1|Item) + AgeGroup + Condition + AgeGroup: Condition. *SE* = standard error.
*** $p < .001$.

Experiment 2

An alternative explanation for the patterns in Experiment 1 was that children (and adults) simply tracked whether the actor in the videos completed or otherwise terminated the depicted action, as opposed to whether the event was truly (un)bounded: in bounded events, the girl was done since the inherent endpoint was always realized; in unbounded events that lacked an inherent endpoint, the girl simply stopped the action (the notion of completion is not applicable). Event completion/termination is different from event boundedness (the presence/absence of an inherent endpoint, whether realized or not; Dahl, 1981; Ji & Papafragou, 2020a). To exclude this possibility, Experiment 2 had the same training phase as Experiment 1; however, in the testing phase, half of the videos showed an entire

[3] We also examined whether Source of Boundedness (Action vs. Affected Object), Testing List, as well as the Gender of participants influenced accuracy. Neither these factors nor their interactions with other factors reliably improved the model fit (based on chi-square tests of change in −2 restricted log likelihood, all *p*s > .150). This suggests that adding these factors did not lead to a better explanation of the variance in accuracy. In other words, performance did not differ in terms of the two types of bounded–unbounded contrast (Action vs. Affected object), or between different lists, or between females and males. Therefore, all the three nontheoretically-driven factors were not included in the final model. The same strategy of model selection was applied to the analyses in the following experiments.

event, as in the previous experiment (full videos), and the other half only showed the very beginning of the event (truncated videos). Full and truncated videos differed in terms of whether the event completion/termination point was visible but not in terms of whether the event was bounded or not. If children (and adults) in the Bounded Condition based their conjectures on event completion after watching full videos during training, they should only accept full videos as members of the target category at the test. However, if participants based their conjectures on whether the event had a potential but not necessarily realized endpoint, they should generalize the target category to both full and truncated videos. Similar predictions apply to the Unbounded Condition: if participants categorized events based on whether the endings (of completion) were visible, later on, they would only accept truncated videos as events of the target category; by contrast, if participants could extract the bounded–unbounded distinction, they would accept both truncated and full videos as long as the videos showed events lacking an inherent endpoint. In a word, the present manipulation allows us to distinguish whether participants tracked event termination or true event (un)boundedness.

Method

Participants

A new group of 40 4–5-year-old children (age range: 4.1–5.4, mean age: 4.8, 22 female, 18 male) and 40 adults (age range: 18.5–21.3, mean age: 19.3, 19 female, 21 male) participated in the experiment. All participants were native speakers of English. Children were recruited at the same local preschools as children in Experiment 1. They were identified as Caucasian (75%, $n = 30$), African American (12.5%, $n = 5$), or Asian (12.5%, $n = 5$). Adults were undergraduates at the University of Delaware and received course credit for participation. The adult sample was 80% Caucasian ($n = 32$), 10% African American ($n = 4$), 7.5% Asian ($n = 3$), and 2.5% unreported ($n = 1$). The sample size was decided based on the calculated power of Experiment 3 in Ji and Papafragou (2020a), which had the same design with 40 participants. The estimated effect size for the predictor of interest, Condition, was −0.93, with a power of 85%. Thus, a sample size of 80 participants would be adequate to achieve 80% power at $\alpha = .05$.

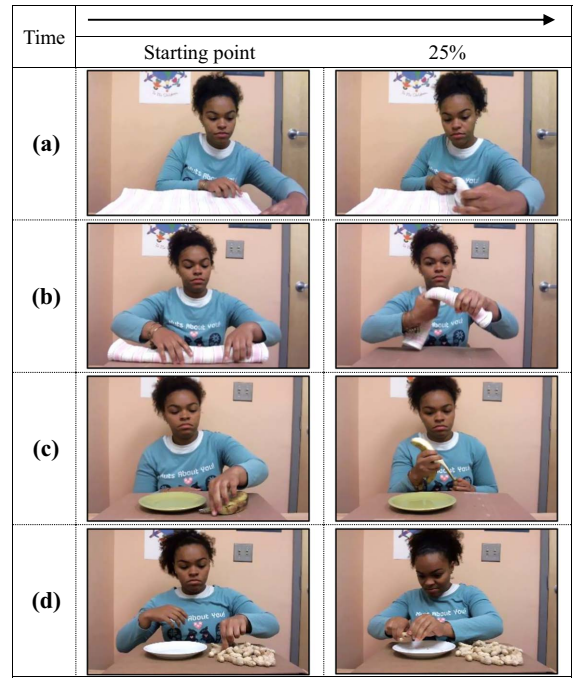
Stimuli

In the training phase, videos were the same as in Experiment 1. In the testing phase, half of the videos were truncated, and the other half were full. The truncated videos were created by editing the eight pairs of videos used in the testing phase of Experiment 1 so that only the first 25% of each video remained. As a result, truncated bounded events were incomplete, while truncated unbounded events were unterminated (Figure 3). The full videos consisted of eight unpaired videos of four bounded events (stack five cups on the table, put some *Q*-tips together, erase a star, organize three pairs of socks by color) and four unbounded events (roll a ball back and forth, grind biscuits, sprinkle pepper, pull a towel).

The truncated videos were arranged into two lists in the same way as in Experiment 1. Then, the eight full videos were added to each list. Each of the resulting testing lists was composed of 16 videos, and whether the event was bounded or unbounded and whether the video was truncated or full was counterbalanced. In each list, there were eight bounded and eight unbounded events; for each event type, four videos were full, and four videos were truncated. The 16 videos were arranged in a pseudorandomized order such that both event types (bounded vs. unbounded) and video types (full vs. truncated) were intermixed.

Figure 3

Examples of Truncated Videos in Experiment 2: (a) Roll up a Towel (Bounded), (b) Twist a Towel (Unbounded); (c) Peel a Banana (Bounded), (d) Crack Peanuts (Unbounded)



Note. See the online article for the color version of this figure.

ONLINE COLOR

Procedure

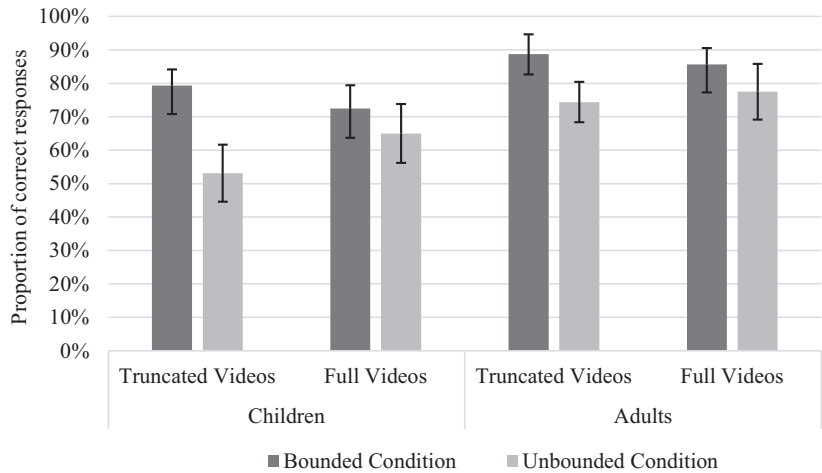
The procedure was identical to that of Experiment 1.

Results

Results from Experiment 2 are shown in Figure 4. The binary accuracy data were analyzed with a mixed logit model, examining the fixed effects of Age Group (Children vs. Adults), Condition (Bounded vs. Unbounded), and Video Type (Truncated vs. Full) and their interactions. The inclusion of Age Group significantly improved the model fit, $\chi^2(1) = 23.19$, $p < .001$; Condition also led to a significant increase in the fit, $\chi^2(1) = 31.11$, $p < .001$. Video Type did not significantly contribute to the model fit, $\chi^2(1) = 0.22$, $p > .250$, but its interaction with Condition did, $\chi^2(1) = 6.85$, $p = .009$.[4] As shown in Table 3, there was a significant effect of Age

[4] We also examined nontheoretically driven factors—Testing List and Gender. Neither these factors nor their interactions with other factors reliably improved the model fit (all *p*s > .230). Therefore, they were not included in the final model.

Figure 4
Proportion of Correct Responses in Experiment 2



Note. Error bars represent ±SEM. SEM = standard error of the mean.

Group (β = −0.78, z = −5.81, p < .001): adults (M = 81.6%) were overall better than children (M = 67.5%). There was also a significant effect of Condition (β = −0.78, z = −5.79, p < .001): performance in the Bounded Condition (M = 81.6%) was better than in the Unbounded Condition (M = 67.5%). Importantly, no significant effect of Video Type was found (p > .250): full and truncated videos were treated similarly by participants. In addition, a significant interaction between Video Type and Condition was detected (β = −0.70, z = −2.58, p = .009): for full videos, there was a better performance in the Bounded (M = 79.1%) than the Unbounded condition (M = 71.3%; β = −0.44, z = −2.27, p = .023), but the effect of Condition was greater for truncated videos (Bounded condition: M = 84.1%, Unbounded condition: M = 63.8%; β = −1.14, z = −5.81, p < .001). Both adults' and children's performance was significantly above chance level across combinations of conditions and video types (all ps < .001), with the exception of children's performance with truncated videos in the Unbounded condition, t(19) = .82, p > .250.

Table 3
Fixed Effect Estimates for Multilevel Model of Identifying the Target Category in Experiment 2

Effect	Estimate	*SE*	*z* value
(Intercept)	1.16	0.08	14.99***
Age group (children vs. adults)	−0.78	0.13	−5.81***
Condition (bounded vs. unbounded)	−0.78	0.14	−5.79***
Video type (truncated vs. full)	−0.01	0.15	0.96
Condition × Video Type	−0.70	0.27	−2.58**

Note. Formula in R: Accuracy ~ 1 + (1|Subject) + (1|Item) + AgeGroup + Condition + VideoType + Condition: VideoType. Only interactions that significantly improved model fit were included in the final model and reported here. *SE* = standard error.
** p < .01. *** p < .001.

Discussion

The results of Experiment 2 show that 4–5-year-old children, like adults, relied on (un)boundedness rather than completion or termination when categorizing events. This means that participants were able to project their inherent endpoint even when seeing only the beginning of the event. The bounded–unbounded asymmetry observed in Experiment 1 persisted. Particularly in the Unbounded condition, performance on full videos was significantly above the chance level, suggesting that children could form an unbounded class, but performance on truncated videos was at the chance level. The interaction between Video Type and Condition suggests that there was a cost of generalizing (un)boundedness to a new type of video stimuli (i.e., the truncated videos), particularly when unbounded events were the target category.

An alternative interpretation of the results from Experiments 1–2 could be that children silently described what they saw and completed the task using their linguistic knowledge of the event language. Recall, however, that this possibility was made unlikely by a prior "shadowing" version of this task (Ji & Papafragou, 2020a). In that study, adults counted numbers throughout the training phase. The results showed that sensitivity to boundedness emerged even when the participants were prevented from encoding the stimuli linguistically. We know that children are less likely than adults to use language strategically in cognitive tasks until about Age 6 or later (Dessalegn & Landau, 2013). Therefore, we take the results of Experiments 1–2 as evidence that both children and adults represent (un)boundedness as part of cognitive event structure.

Experiment 3

Experiments 1 and 2 showed that 4–5-year-old children regard bounded and unbounded events as different categories. Experiment 3 asked whether children's sensitivity to the bounded–unbounded distinction has further psychological consequences for how unfolding events are processed. Specifically, we adopted a variant of the "picky puppet task" (Ji & Papafragou, 2020b; Waxman & Gelman, 1986). During training, 4–5-year-old children

and adults watched videos containing an interruption that blurred either the midpoint or the endpoint of an event and were introduced to a picky girl who liked only one of these blurred versions but not the other. At the test, participants were asked whether the girl would like new videos containing mid- or end-interruptions.

We expected that the ability to learn the picky girl's (ostensibly arbitrary) preference would be driven by the 4–5-year-olds' (and adults') own biases when processing bounded versus unbounded events. For bounded events, both 4–5-year-olds and adults would have different reactions to the girl's preference for midpoint versus endpoint interruptions. Specifically, for both groups, it would be harder to learn that the picky girl prefers endpoint compared to midpoint interruptions since endpoint interruptions occluded the salient climax of the event. For unbounded events that have no clearly defined endpoints, however, both groups should learn the picky girl's preference with little or no difference between preference for midpoint and endpoint interruptions.

Method

Participants

A new group of 80 English-speaking children (age range: 4.0–5.5, mean age: 4.8, 34 female, 46 male) and 80 English-speaking adults (age range: 18.1–21.4, mean age: 19.4, 40 female, 40 male) participated in the experiment. Participants were recruited from the same populations as in previous experiments. Child participants were identified as Caucasian (76.3%, $n = 61$), African American (21.3%, $n = 17$), or Asian (2.4%, $n = 2$); adult participants identified their race as Caucasian (73.8%, $n = 59$), African American (18.8%, $n = 15$), Asian (6.2%, $n = 5$), or American Indian (1.2%, $n = 1$). Data from five additional children and one adult were collected but excluded because their responses consisted exclusively of *Yes* responses. The sample size was decided based on the calculated power of the experiment by Ji and Papafragou (2018), which had the same design with 80 adult participants. The predictor of interest was the interaction between Preference (Likes mid- vs. end-interruption) and Event Type (Bounded vs. Unbounded). The estimated effect size of this predictor was 1.52, with the power at 95%. Therefore, 160 participants would be adequate to achieve 80% power at $\alpha = .05$.

Stimuli

The video stimuli were composed of 20 bounded events and 20 closely paired unbounded events (see Table 4). The events were similar to those used in previous experiments. Paired bounded–unbounded videos (i.e., each row in Table 4) had the same duration (range: 4.5–13 s, $M = 7.2$ s) and showed events that differed in either the action (e.g., open a towel vs. twist a towel) or the affected object (e.g., paint a heart vs. paint stuff). To increase the visual variety of the stimuli, we created an additional version of the videos that was identical to the first, except that the actor wore clothes of a different color.

All of the videos were then edited in Corel VideoStudio X9 to introduce an interruption taking up one-fifth of the total video duration (range: 0.9–2.6 s, $M = 1.44$ s). During the interruption, a blurry picture appeared on the screen. To create the blurry picture, we selected the midpoint frame (for interruptions in the middle) or endpoint frame (for interruptions at the end) in the original video and then applied an Iris Blur Effect in Adobe Photoshop Creative Suite 6 (see the examples in Figure 5). Each video was edited twice, once to create a mid-interruption and once to create an end-interruption. The mid-interruption was centered on the video midpoint, while the end-interruption blocked the last 20% of the video.

Procedure

Participants were randomly assigned to one of two Event-type conditions; that is, they were exposed to either Bounded or Unbounded events throughout the experiment. The experiment was composed of a training and a testing phase. At the beginning of the training phase, the experimenter invited participants to watch a couple of videos and told them that the girl in the videos liked performing but was very picky about her videos: she liked some videos but not others. The task was to figure out what kind of videos the picky girl liked. Participants watched a total of 16 videos. Each time, a video is played in the center of the screen. The 16 videos were comprised of eight events (No. 1–8 in Table 4 for bounded events, or 21–28 for unbounded events, presented in random order), each with two versions shown in succession. The two versions differed in terms of both the actor's clothes color and in terms of the placement of the interruption (mid-interruption vs. end-interruption; see Figure 5 for an example). Within this phase, half of the time, mid-interruptions occurred with one clothes color, and the rest of the time, they occurred with the other color. Even though our hypothesis targeted the detection of a mid- versus end-interruption, we added the change of clothes color to ensure that participants would treat the two (highly similar) versions of each event as different tokens. The order of mid-interruptions and end-interruptions, as well as clothes colors, was counterbalanced.

After each version, the experimenter said, "The girl likes the video," or "The girl doesn't like the video." To highlight the picky girl's attitude toward the video, a smiley face or an angry face appeared on the screen, respectively. Within the Bounded and Unbounded group, participants were randomly assigned to one of two Preference conditions. In the "Likes mid-interruption" condition, they always heard that the picky girl liked the video and saw a smiley face after mid-interruptions, but they also heard that the girl did not like the video and saw an angry face after end-interruptions. In the "Likes end-interruption" condition, the girl's preference was reversed. Participants were expected to detect the girl's preference based on the placement of interruptions.

In the testing phase, participants watched a total of 12 videos showing 12 new events (No. 9–20 in Table 4 for bounded events or 29–40 for unbounded events, presented in random order). Half of these events were presented in their mid-interruption version and the other half in their end-interruption version. Each event type (bounded vs. unbounded) had four lists; participants were randomly assigned to one of the four lists. Each list included one interruption version (mid- or end-) of each event; the actor's clothes color was counterbalanced for that event across lists. Types of interruptions and changes in clothes color were evenly split within each list. After watching each video, participants were asked: "Will the girl like this video or not?" Child responses were recorded by a research assistant. Adult participants wrote down a *Yes/No* response on an answer sheet.

Results

Correct responses indicated that participants could identify the type of interruptions that the picky girl liked. For instance, in the

Table 4
Event Stimuli in Experiment 3

Phase	No.	Bounded event	No.	Unbounded event
Training	1	Draw a fish	21	Draw circles
	2	Paint a heart	22	Paint stuff
	3	Drink up a cup of juice	23	Drink/sip water
	4	Cover a slice of bread with peanut butter	24	Cover slices of bread with peanut butter
	5	Cut a piece of paper in half	25	Cut ribbon from a roll
	6	Peel an orange	26	Crack peanuts
	7	Open a towel	27	Twist a towel
	8	Fill a glass with milk	28	Shake a bottle of milk
Testing	9	Eat a candy	29	Eat cheerios
	10	Break a biscuit (into two pieces)	30	Grind biscuits
	11	Blow a balloon	31	Blow bubbles
	12	Tear a paper towel	32	Tear slices off paper towels
	13	Tie a knot	33	Tie knots
	14	Clean a mirror	34	Clean/brush teeth
	15	Make a letter with ketchup on a plate	35	Sprinkle pepper on a plate
	16	Roll up a towel	36	Pull a towel
	17	Fold up a handkerchief	37	Wave a handkerchief
	18	Peel an egg	38	Beat an egg
	19	Scoop up yogurt	39	Stir yogurt
	20	Stack 5 cups on the table	40	Roll a ball back and forth

Note. Paired videos appear in the same row.

"Likes mid-interruption" condition, the correct answer was *Yes* for a video with a mid-interruption and *No* for a video with an end-interruption. If participants failed to connect the girl's preference with the placement of the interruption, the proportion of the correct responses would be around the chance level. Furthermore, if participants based their conjecture on the color of the girl's clothes, they should give a correct response around half of the time (since color was counterbalanced). As shown in Figure 6, for both children and adults, the proportion of correct responses significantly differed from chance level in both Preference conditions and across both Event types (all ps $< .01$). This suggests that, overall, participants could track the placement of interruptions as expected and were not distracted by other factors such as the change in the color of the girl's clothes.

The binary accuracy data were analyzed with a mixed logit model examining the fixed effects of Age Group (Children vs. Adults), Preference (Likes mid-interruption vs. Likes end-interruption), and Event Type (Bounded vs. Unbounded). All of the factors were coded using centered contrast (−0.5, 0.5). Adding Age Group and Preference significantly improved the model fit; Age Group: $\chi^2(1) = 81.56$, $p < .001$; Preference: $\chi^2(1) = 12.11$, $p < .001$. The inclusion of Event Type did not lead to a significant increase in the model fit, $\chi^2(1) = 0.24$, $p > .250$, but its interaction with Preference did, $\chi^2(1) = 9.25$, $p = .002$.[5] As shown in Table 5, the model revealed an effect of Age Group ($\beta = -1.45$, $z = -9.69$, $p < .001$); adults (M = 90.5%) were overall better at figuring out the picky girl's preference than children (M = 70.5%). There was also a significant effect of Preference ($\beta = -0.51$, $z = -3.67$, $p < .001$): participants were more accurate when the picky girl liked mid-interruptions (M = 84.0%) compared to end-interruptions (M = 77.1%). No significant effect of Event Type was found ($p > .250$). Importantly, a significant interaction between Preference and Event Type was detected ($\beta = 0.84$, $z = 3.01$, $p = .003$): participants exposed to bounded events were better at identifying a preference for mid-interruptions (M = 87.1%) compared to a preference for end-interruptions (M = 74.6%; $\beta = -1.01$, $z = -3.97$, $p < .001$); by contrast, participants exposed to unbounded events were equally good at identifying that the girl liked mid-interruptions (M = 80.8%) and end-interruptions (M = 79.6%; $\beta = 0.08$, $z = -0.50$, $p > .250$).

Table 5
Fixed Effect Estimates for the Multilevel Model of Accuracy in Identifying the Preference for Interruptions in Experiment 3

Effect	Estimate	*SE*	*z* value
(Intercept)	1.64	0.08	20.26***
Age group (adults vs. children)	−1.45	0.15	−9.69***
Preference (likes mid- vs. end-interruption)	−0.51	0.14	−3.67***
Event type (bounded vs. unbounded)	−0.11	0.14	−0.79
Preference × Event Type	0.84	0.28	3.01**

Note. Formula in R: Accuracy ~ 1 + (1|Subject) + (1|Item) + AgeGroup + Preference + Event Type + Preference: Event Type. Only the interactions that significantly improved the model fit were included in the final model and reported here. *SE* = standard error.
** $p < .01$. *** $p < .001$.

Discussion

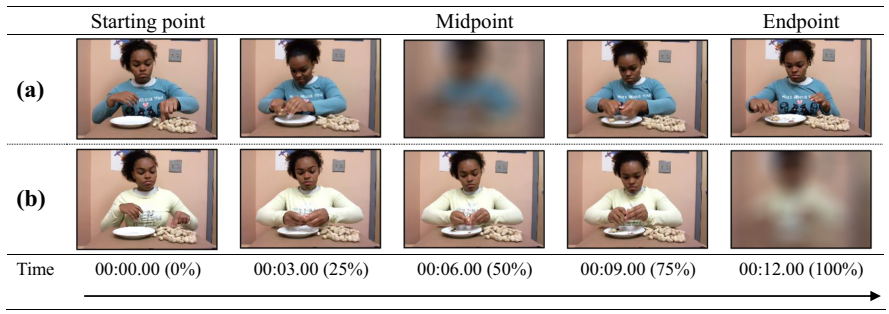
The data from Experiment 3 show that 4–5-year-old children (as well as adults) processed bounded and unbounded event representations differently. Crucially for present purposes, children had more difficulty learning that someone liked end-interruptions compared to mid-interruptions of bounded events, but no such endpoint-midpoint difference was found for unbounded events. These results show that the boundedness profile of an event has consequences for how the event and its various temporal stages are apprehended. Recall that, by hypothesis, bounded events have distinct temporal subparts leading to a climax; by contrast, the internal composition of unbounded events lacks a distinct endpoint. Our results show that, as predicted by this hypothesis, children treat distinct temporal slices of bounded events differently, unlike those of unbounded events.

Could the bounded–unbounded distinction be reduced to the presence of repetition in unbounded but not bounded stimuli? This is unlikely for two reasons. First, whether an action is repeated or not actually cannot differentiate bounded from unbounded events. In this experiment, around one-third (six out of 20) of the bounded instances also involved repetition (see Table 4). For instance, in the case of stacking five cups on the table, the actor repeated the action of putting one paper cup on another. Second, if participants were simply sensitive to repetitive versus nonrepetitive actions, the interruption in a repetitive action would be easier to process since one could

[5] We also examined whether Gender, Clothes Color, Placement of the Interruption (Mid vs. End) and List would influence accuracy. Adding these nontheoretically driven factors to the model did not reliably improve the fit (all ps $> .250$). Therefore, they were not included in the final model.

Figure 5

Example of a Training Trial for an Unbounded Event (Crack Peanuts) That Includes the Two Versions of the Event: (a) Mid-Interruption (Actor in Blue Shirt), (b) End-Interruption (Actor in Yellow Shirt)



Note. The still-frame images were extracted from the video stimuli at different time points corresponding to different stages (0%–100%) of the unfolding event. See the online article for the color version of this figure.

infer the interrupted portion from other subparts. Therefore, it would be easier to detect the picky girl's preference in the Unbounded Condition. This prediction turned out to be incorrect.

General Discussion

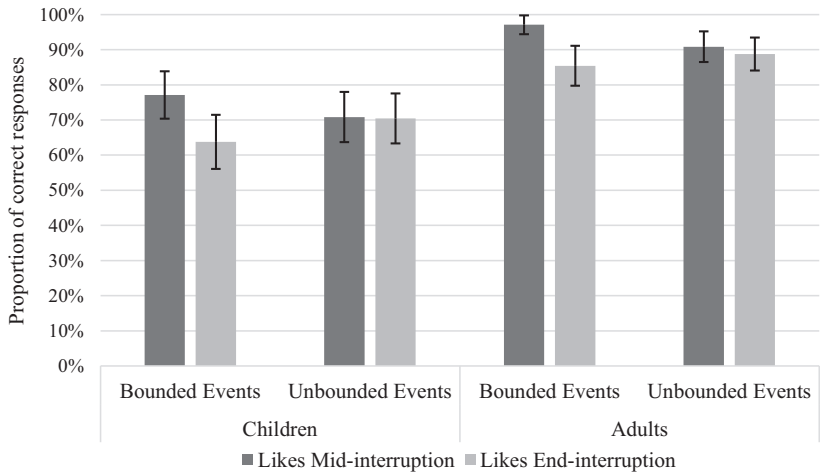
Our findings show that 4–5-year-old children represent the internal temporal structure of events; that is, they can form categories of bounded events (those leading toward an inherent moment of culmination) and unbounded events (those without a specified endpoint; Experiment 1). Furthermore, children at this age are able to treat (un)boundedness (i.e., the availability or lack of an inherent endpoint) as different from event completion or termination (Experiment 2). Last, children treat temporal landmarks such as midpoints and endpoints differently depending on event structure: they react differently to midpoint and endpoint interruptions in what they consider a bounded event, but not in an unbounded event, thereby showing that (un)boundedness has psychological effects for event processing (Experiment 3). Below, we discuss the implications of these results for early event cognition and language.

Delimiting Events and Their Boundaries

Our results bear on the mechanisms and development of event cognition since they suggest that young children's event representations include a highly abstract construal of event temporal structure. Recall that whether an event was thought to contain "a beginning, midpoint and endpoint" predicted children's classification of the event, suggesting that children were sensitive to the precise nature of event endpoints. Our findings show continuity in mechanisms of event cognition since the shape of results was overall similar between

Figure 6

Proportion of Correct Responses in Experiment 3



Note. Error bars represent ±SEM. SEM = standard error of the mean.

4–5-year-olds and adults despite lower accuracy in children's performance (cf. Ji & Papafragou, 2020a).

Unlike past developmental work on event segmentation that has focused on how children divide continuous actions into discrete events (Baldwin et al., 2001; Hespos et al., 2009; Meyer et al., 2011; Pace et al., 2013; Saylor et al., 2007; Stahl et al., 2014; Y. Zheng et al., 2020, cf. Radvansky & Zacks, 2014; Zacks & Tversky, 2001), the present approach reveals children's generalizations about the representational content of individual events and the way events are related to one another. We show that 4–5-year-old children are able to form an event *category* across visually dissimilar events (e.g., drawing a balloon and rolling up a towel vs. drawing circles and twisting a towel) based on the way these events are thought to unfold over time and come to an end; they can further generalize the category to examples where the endpoint is not visible. Moreover, children (like adults; Ji & Papafragou, 2020a) rely on both the nature of the action and the quantization of the affected object to form (un)boundedness construals. On the present approach, the property of (un)boundedness goes beyond the factors that have been taken to characterize event breakpoints within event segmentation models: it is neither reducible to lower-level perceptual features of the stimuli (given the visual variability of our stimuli) nor is it identical to higher-level conceptual features such as intentionality (since videos of both bounded and unbounded events depicted intentional actions to the same degree; see the norming data in Experiment 1). As already alluded to, we take the cognitive ability to distinguish between bounded and unbounded event construals to be foundational for how children represent temporal entities in the world, just like the cognitive ability to distinguish between objects and substances is foundational for how children represent spatial entities.

The parallel between events and objects, long noted in both the linguistic and philosophical literature (see Bach, 1986; Jackendoff, 1991; cf. also Barner & Snedeker, 2006; Wagner & Carey, 2003; Wellwood et al., 2018), can help explain one of our most robust findings in both categorization experiments: namely, the consistent advantage of bounded over unbounded events for both children and adults (cf. also Ji & Papafragou, 2020a; and especially Papafragou & Ji, 2023). We propose that the advantage of the bounded event category can be attributed to atomicity, a property that bounded events share with objects (cf. the Introduction section). Bounded events (expressed by telic verb phrases such as *peel a banana*), just like objects (expressed by count nouns such as *a peanut*), are naturally individuated "atoms." Similar to objects that are measured by counting their number (e.g., one can count how many peanuts there are in a jar), bounded events can be quantified by counting the number of inherent endpoints that have been achieved (e.g., one can measure the occurrence of banana-peeling events by counting how many bananas have been peeled; Barner et al., 2008; Wagner & Carey, 2003). Unbounded events (expressed by atelic verb phrases such as *peel bananas*), just like substances (expressed by mass nouns such as *peanut butter*), are unspecified for atomic features. Neither unbounded events nor substances can be directly counted; additional criteria are needed to turn these entities into something countable (e.g., peanut butter can be measured and compared by weight; peeling bananas can be quantified by the duration of the activity, among other possibilities). Our data show that, across development, temporal entities that are considered individuated or "atomic" (bounded events) behave differently from temporal entities that are considered unspecified for these features (unbounded events)—for instance, they are more easily tracked and abstracted over.

(Un)Boundedness and Event Processing

Previous literature on event cognition has converged on the finding that children—as well as adults—encode endpoints as a critical event component in both language and memory (e.g., Lakusta & Landau, 2005, 2012; Papafragou, 2010; Regier & Zheng, 2007; Strickland & Keil, 2011; Zacks & Swallow, 2007). The present work expands on and offers a framework for explaining this finding by showing that the role of event endpoint shifts depending on the overall event architecture (see especially Experiment 3). Specifically, the salience of endpoints is connected with the structure of bounded events; in unbounded events that terminate but do not culminate (and in principle could iterate indefinitely), endpoints are treated largely similarly to other temporal pieces such as midpoints. Thus, the internal temporal contour of events determines how different event segments are processed as the events unfold. At their broadest, these results show that boundedness, a formal property of event representations that was inspired by the linguistic and philosophical literature on the aspect (Hinrichs, 1985; Krifka, 1998; Vendler, 1957), has psychological implications for how children (and adults) process and compare between different time points of ongoing events.

As already highlighted in the Introduction section, we take boundedness to be a mental perspective on events rather than an objective feature of the dynamic input. This is in line with the widely accepted view that situations "out there in the world" do not have any intrinsic temporal structure; instead, our mind represents those situations as structured events with different temporal profiles (Zacks et al., 2007) and our linguistic descriptions encode event structure through the aspectual system (Filip, 1999; Parsons, 1990). The same situation may be construed as either a bounded or an unbounded event and be described with either a telic or an atelic verb phrase. However, it is important to note that those event construals (as well as descriptions) are not equally plausible, and people are often biased toward one construal over the other. Inspired by the vast linguistic analyses of the factors that determine telicity, in the present study, we focused on two cues, namely the nature of the action and the quantization of the affected object when designing our stimuli (see also Ji & Papafragou, 2020a, 2022). As the present data show, children can also rely on these cues to form boundedness categories and process the temporal structure of ongoing events.

The present data leave a few questions open for future research. First, our study did not examine factors that may determine boundedness construals in an exhaustive way. The next steps of research should disentangle the effects of the two visual cues to better understand their nature and further explore the contributions of other perceptual and conceptual factors to how children and adults organize dynamic input into bounded or unbounded event units. Second, the results from our experiments did not reveal *how early* children extract the abstract property of boundedness from specific event items. We know that adults compute (un)boundedness during online event perception, even when it is irrelevant to the task (Ji & Papafragou, 2022). Future research may develop appropriate

methods to investigate event perception in young children. Last but not least, since boundedness is a mental perspective on the temporal structure of perceived events, it is worth asking whether and how the current event construals may shift (for a related question with adults, see Vurgun et al., 2023).

(Un)Boundedness in Early Cognition and Language

Finally, our results demonstrate that boundedness is a foundational conceptual distinction that represents a basic commitment to the kind of event a young learner has in mind. The current data suggest a close relation between the conceptual and linguistic representation of event temporal structure. Early sensitivity to boundedness could lay the foundations for the acquisition of aspect in language (Filip, 1999; Wagner, 2009). In that sense, our results support the claim that event language is parallel to and draws from event cognition (see also Cohn et al., 2017; Folli & Harley, 2006; Gleitman, 1990; Hafri et al., 2013; Jackendoff, 1990, 2007, Chapter 4; Lakusta & Landau, 2005; Malaia, 2014; Papafragou, 2015; Papafragou & Grigoroglou, 2019; Pinker, 1989; Strickland et al., 2015; Tversky et al., 2011).

Given that boundedness is encoded in different ways across languages (Bar-El et al., 2005; Botne, 2003; Filip, 2004; Friedrich & Gateva, 2017; Kardos, 2016; Singh, 1998; Soh & Kuo, 2005; Zhang, 2020), and that these differences affect the acquisition of aspect (e.g., Hacohen, 2012; Stoicescu & Dressler, 2022; van Hout, 2007), it remains to be seen how children's nonlinguistic boundedness generalizations interface with the development of aspectual distinctions. There are various possibilities for how the two notions develop in young learners. One possibility is that conceptual boundedness precedes and structures the linguistic encoding of boundedness. This hypothesis predicts that nonlinguistic event boundedness would be conceptualized in similar ways cross-linguistically. To test this prediction, future research could adopt nonlinguistic experiments similar to our own and test children whose native language differs from English in the ways of encoding telicity; an additional way to examine the direction of causation is to test whether boundedness could be computed by learners without exposure to a conventional linguistic system (e.g., deaf homesigners; Feldman et al., 1978; M. Zheng & Goldin-Meadow, 2002). Alternatively, the conceptual signature of boundedness might arise because of familiarity with the way boundedness is encoded in the viewer's language. This would predict that children speaking different languages may have different boundedness construals, corresponding to the cross-linguistic differences in encoding aspectual properties. A third possibility is that, beyond shared initial construals of boundedness, language-specific aspectual knowledge may shape or constrain later representations of event boundedness in children. This would predict that the maturation of aspectual knowledge may help form more complex and refined conceptual representations of event boundedness in children.

Conclusions

We conclude that young children represent foundational and abstract properties of event temporal structure in ways that align with the encoding of the temporal profile of events in language. Such sensitivity to the internal temporal profile of events can further support the way children conceptualize and process their dynamic experiences.

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