Event Processing as an Executive Enterprise

ROBBIE A. ROSS and DARE A. BALDWIN

Abstract

Actual experience as life unfolds tends to be an ebb and flow of dynamic, multimodal sensations, many of which are fleeting. Yet what is encoded, recalled, and talked about tends to be events—units of experience that are conceptualized as having both a beginning and an end. In this essay, we consider processing mechanisms that enable the extraction of event structure from the dynamically unfolding stream of experience. Two proposals emerge from our own and others' recent research on event processing: First, fluent detection of structure within activity streams appears to hinge on knowledge of the predictability relations within those streams. Second, skill at event processing seems to involve harnessing such knowledge of predictability relations to selectively direct attention to information-rich portions of the activity stream. If this account is correct, individual differences in knowledge and executive skill should influence event-processing fluency. As well, children's developmental progress in event processing should reveal the telltale impact of increasing knowledge and executive skill. Our hope is that research pursuing these ideas will ultimately make it possible to enhance event-processing fluency for all, which in turn has the potential to facilitate memory, learning, and social interaction.

EVENT PROCESSING AS AN EXECUTIVE ENTERPRISE

BANGvooshsploshyowlskitterdripdropdrip.driip..ddrriipp. This rendition of a genuine recent life occurrence is intended to showcase that experience as it unfolds across time is dynamic, complex, multimodal, and ephemeral. As sensory information flows past, we grasp its significance as best we can and retain whatever possible to guide understanding and future action. During the course of this ongoing processing, we tend to have the sense that the stream of information is punctuated by events—coherent units with identifiable beginnings and endings—that possess inherent structure, such as sequential, hierarchical, causal, and/or intention/goal structure. In the example, a feline-enriched personal history might help one to interpret the dynamic sensory flow as yet another instance of a sensation-seeking cat's

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penchant for knocking over water-filled vases (discrete event 1), with the inevitable consequences of fright (2), flight (3), and telltale water damage (4).

The particular event structure we derive from the sensory stream of experience seems to constitute our understanding of that experience. Increasing evidence indicates that are involved in this ongoing process of event redescription. These processes appear to include flexible allocation of attention to information-rich regions within unfolding experience. The central aims for this chapter are to review such recent insights into the nature of event-processing mechanisms, and to consider how executive skills, such as selective attention, seem to guide event processing and may thus play an integral role in how event processing changes with learning and development.

As described, unfolding experience tends to be interpreted in terms of discrete events, despite the fact that change in the world is dynamic and largely continuous. The event boundaries we identify are not random or purely idiosyncratic, however. When asked to identify meaningful junctures in a flow of activity, as viewers we display substantial agreement regarding where events begin and end (Newtson, 1973). When intentional human action is involved, these boundaries tend to coincide with goal transitions (Baldwin & Baird, 2001; Zacks, 2004; Zacks & Tversky, 2001). Identification of segmental structure occurs at multiple levels of scale that we organize into partonomic hierarchies, with fine-grained, temporally brief event-elements nested within successively higher order event segments (Newtson, 1973; Zacks, Tversky & Iyer, 2001). Several sources of evidence using both behavioral (Hard, Recchia, & Tversky, 2011; Huff, Papenmier, & Zacks, 2012; Saylor & Baldwin, 2004) and neuroimaging (Zacks *et al*., 2001, Zacks, Swallow, Vettel, & MacAvoy, 2006) methods indicate that these event segmentation processes are automatic aspects of our default processing of experience.

A new methodology—the dwell-time paradigm (Hard *et al*., 2011)—shows particular promise for illuminating mechanisms subserving event processing. In this paradigm, slideshows are constructed by extracting frames at regular intervals (e.g., 500 ms) from digitized videos of unfolding activity. Viewers click a computer mouse to advance through these slideshows at their own pace; the latency between clicks reflects their dwell times to each slide.

Prior work documents systematicity in viewers' dwell times indicative of sensitivity to segmental structure within the activity stream (Hard *et al*., 2011). Specifically, dwell times are longer to slides coinciding with event boundaries (as identified by either participants themselves on a subsequent viewing, or by others) relative to slides depicting within-event content. Dwell-time patterns also reflect hierarchical organization of segmental structure; that is, viewers tend to dwell longest on slides depicting higher order event boundaries and progressively more briefly to slides depicting lower level event boundaries. Moreover, the extent of dwelling on higher order event boundaries predicts recall for the activity stream, demonstrating that segmentation and/or hierarchical organization processes predict memory for events (Hard *et al*., 2011).

The characteristic dwell-time patterns just described emerge for a broad range of event types, including full-body intentional action (Hard *et al*., 2011; Meyer, DeCamp, Hard, Baldwin, & Roy, 2010), fine-grained manual activity (Sage & Baldwin, 2014), and dynamic facial-emotion displays (e.g., Garrison & Baldwin, 2014). Thus, similar processing strategies seem to guide at least some aspects of event processing across domains and differences of scale. Children as young as 2 to 3 years of age display dwell-time patterns comparable to adults' (Baldwin & Sage, 2013; Meyer, Baldwin, & Sage, 2011), at least when children are given relatively familiar, developmentally appropriate event stimuli to view. The fact that children display dwell-time patterns indicative of segmentation and hierarchical organization of segments both showcases the usefulness of the dwell-time paradigm with children as well as adults, and points to event processing possessing a similar character, at least with respect to segmentation phenomena, across a relatively broad developmental span.

Speaking in general terms, dwell-time patterns appear to index the ongoing modulation of selective attention as activity unfolds across time. But why does dwelling increase systematically at event boundaries? This is as yet not entirely clear. Hard and colleagues (2011) have suggested that event boundaries may serve as "conceptual bridges" from one event to the next. If this is correct, then viewers' ability to systematically direct attention to boundary regions within events is an important aspect of fluent event-processing skill.

This proposal—that selective attention to event boundaries is crucial to fluent event processing—has several implications. First, it suggests that knowledge or expertise is involved in the fluency of event processing; that is, without prior knowledge it is unclear how viewers could discern which portions of the complex, dynamic stream of sensory stimuli are especially information rich. Second, this proposal suggests that executive function skill—skill that, among other things, makes it possible to mobilize attention to selected targets or specific regions within temporal sequences—is central to fluent event processing. In other words, skill at attention modulation presumably is required to systematically direct attention to relevant regions within unfolding sensory streams. Relatedly, we might expect executive function deficits to impair fluent event processing. Third, the proposal leads us to expect developmental change in the fluency of event processing, because knowledge and executive skill both increase substantially during childhood. In what follows we discuss available evidence pertinent to these suggestions, and outline research we are beginning to undertake to investigate the issues further.

EXPERTISE IN EVENT PROCESSING

The proposal is that viewers spontaneously increase attention to event boundaries, which are points within unfolding sensory stimuli at which one segment transitions into the next. An alternative possibility, however, is that this upregulation of attention occurs simply because event boundaries are in some inherent way attention attracting. That is, these boundary regions within unfolding information might naturally draw viewers' attention without viewers playing any agentive role in targeting these regions with selective attention. As we explain below, this alternative account is plausible, but even at this early phase of investigation the available evidence suggests that it does not fully capture event-processing phenomena.

Existing evidence suggests that there indeed may be perceptual concomitants of event boundaries that potentially draw viewers' attention exogenously. For example, segment boundaries appear to probabilistically coincide with changes in line-of-regard, the particular object contacted, directionality of motion, as well as the sheer magnitude of physical motion change and motion dynamics such as velocity and acceleration parameters (e.g., Baldwin & Baird, 1999; Hard *et al.*, 2011; Newtson, Enquist, & Bois, 1977; Zacks, 2004; Zacks & Swallow, 2007; Zacks, Swallow, *et al.*, 2006). Any one, or any combination, of these physical, perceptual occurrences within unfolding experience might systematically elicit increased attention from viewers.

Interestingly, however, inherent salience seems not to be the only reason viewers increase attention to event boundaries. Knowledge appears also to play a key role. A recent study that married statistical learning with the dwell-time paradigm provided the first direct evidence to this effect (Baldwin, Hard, Meyer, & Sage, 2014). The stimuli employed in the research were novel event sequences specifically designed such that salient perceptual characteristics did not correlate in any way with event boundaries. Rather, statistical regularities were the only clue to segment boundaries. Findings from the research revealed that viewers' dwell times became reorganized as knowledge of the statistically based segmental structure of the event sequence grew across time. Once knowledge of the statistics was gained, viewers displayed the classic segment-related dwell-time patterns observed in prior dwell-time research: they attended longer to slides depicting (statistically defined) segment boundaries than to slides depicting mid-segment content. Before having gained knowledge of the statistics, viewers' dwell times lacked this segment-related increase in dwell times. Strikingly, viewers' ability to successfully identify intact event segments relative to nonsegment foils in a discrimination task was related to dwell-time patterns in their prior slide-show viewing: those who displayed a strong knowledge of segmental structure in the discrimination task displayed enhanced dwell times at segment boundaries, whereas dwell times were unrelated to segment boundaries among those who performed poorly on the segment discrimination task. All in all, these findings clearly showcase that increasing knowledge of an event sequence, and of its segmental structure in particular, alters how attention is allocated as viewing of the sequence unfolds.

Again, one might ask why greater attentional resources appear to be allocated to regions of a sensory stream where one event ends and the next begins. Are such regions especially information rich? Zacks and colleagues (Zacks, Kurby, Eisenberg, & Haroutunian, 2011) have provided some evidence that the culmination points of event segments tend to be junctures when predictability plummets within the unfolding flow of experience. To explain: Any number of new activities could follow when an event segment is completed. For example, when placing a coffee mug onto a table (as at the end of a *taking a sip of coffee* segment) it is challenging to predict what will occur next, as a range of possible event segments could ensue, such as *taking another sip of coffee, taking a bite of food, getting up from the table, pouring more coffee into a cup, making conversation*, and the like. In contrast, just as the next segment is launched and identified, let us say *taking a bite of food*, much of what occurs is highly predictable until the completion of that segment has been reached. Thus, in information-theoretic terms (e.g., Prokhorov, n.d), the transition from one segment to the next is, by virtue of its unpredictability, highly informative. However, a viewer can recognize and selectively attend to such highly informative junctures within an unfolding sensory stream only if in possession of at least some prior knowledge of the predictability structure of the sequence. That is, given some knowledge of the sequence at hand, segment boundaries become "predictably unpredictable," and can be selectively attended to for their heightened information value. Presumably, this is the basis for the reorganization of attention that occurs as knowledge about a sequence grows over time, as observed in the study reported earlier. Consistent with this account, Hard and colleagues (2011) found that dwell times tend to increase shortly before the end of a segment, and continue to display elevation for a short period after the next segment begins; that is, viewers appear to anticipate the occurrence of the predictably unpredictable, information-rich boundary regions, and continue to attend at high levels until predictability resumes mid-segment. Such anticipations were presumably observed in Hard and colleagues' research because they utilized event sequences that were relatively familiar to viewers (e.g., room cleaning, and the like). To the extent that viewers are radically unfamiliar with an unfolding sequence, likely they would be unable to selectively target event boundaries by upregulating attention in anticipation, because they would not be able to predict when a given event segment was likely to be completed. This is a prediction that we are examining directly in research led by Jessica Kosie that is currently under way.

POSSIBLE EXECUTIVE SYSTEM INVOLVEMENT

As described, a key assumption underlying the account offered here for characteristic dwell-time patterns is that viewers systematically (although not necessarily consciously) direct their attention to information-rich segment boundaries as events unfold. How might such ongoing attentional modulation be achieved, however? It seems likely that the executive system, which plays a central role in driving attentional control (e.g., Shallice, 1994), is heavily involved.

The attentional control network is often broadly described as a cognitive system via which individuals selectively attend to relevant sensory input and ignore irrelevant information. When observing unfolding events, the attentional control system may be monitoring the predictability of the event stream and flexibly modulating the viewer's attention as predictability changes. Our existing findings utilizing the dwell-time paradigm seem to confirm this, as does Zacks and colleagues' research, described earlier, showcasing links between adults' processing of event structure and changes in event predictability (Zacks *et al.*, 2011). The executive system is likely upregulating attention to the points in the unfolding sequence that the viewer expects to be most relevant or information rich and simultaneously downregulating attention to less relevant or informative parts of the event. Throughout this complex processing task, the attentional control system is also incorporating accrued knowledge of the observed predictability structure of the event into long-term memory, thereby helping to further enrich event-related knowledge, and facilitating processing of similar event sequences encountered on future occasions.

On this analysis, deficits in executive function would be expected to be related to impaired event-processing fluency. Preliminary evidence to this effect is already available. In a 2006 study, Zacks and colleagues investigated event segmentation patterns and subsequent memory among adults with dementia of the Alzheimer's type, a neurocognitive disorder marked by impaired memory, attention, and other executive functions (Zacks, Speer, Vettel & Jacoby, 2006). They found that, in a task in which participants were asked to watch movies of everyday goal-directed activities and identify where action boundaries exist, the boundaries identified by aging adults diagnosed with dementia were markedly discrepant from those identified by healthy older adults and younger adults, suggesting an impairment in the ability to fluently identify segmental structure within ongoing events. In addition, among older adults, the extent to which event segmentation boundaries agreed with normative boundary selections positively predicted memory performance.

These findings provide additional evidence that appropriately segmenting ongoing events is crucial for proper encoding and recall. Moreover, they suggest a rather new conceptualization of the cognitive deficits occurring in dementia. In particular, they point to difficulties in fluent event processing arising from executive deficits as central in the cognitive profile of dementia, and possibly even responsible for the memory deficits typically viewed as characteristic of the disability. Put another way, memory deficits seen among older adults with dementia may be due in some significant measure to executive system deficits, rather than to memory problems, per se. That is, deficits in the attentional control network may undercut effective attentional modulation to the predictability contour of an unfolding event, rendering a poorly articulated grasp of event structure in those with dementia, and as a result, poor event encoding.

This interpretation of Zacks and colleagues' findings predicts other relations between the executive system and event-processing patterns. For one, other forms of executive deficit, such as that typically seen in those with attention-deficit/hyperactivity disorder (ADHD), might also be linked to event-processing impairments. We are currently undertaking research to examine this possibility. In particular, we are investigating whether severity of ADHD symptomatology predicts (i) impairment in identifying event boundaries in an explicit segmentation task, and (ii) reduction in implicit dwell-time patterns indicative of sensitivity to the segmental and hierarchical structure of events. If these predictions are borne out, it would provide among the first available evidence that fluent event processing is impaired in ADHD, which in turn may help to account for some of the learning and memory difficulties known to be associated with ADHD.

DEVELOPMENTS IN EVENT PROCESSING

A classic developmental question is to wonder how newborn infants experience the sensory flow that, as adults, we so effortlessly interpret in terms of discrete, organized, and meaningful events. Considerable research now clarifies that newborns demonstrate organized and adaptive perceptual processing (e.g., Maurer & Maurer, 1988), but it is only recently that researchers began to question whether infants this young experience events as sequences comprised of discrete units. As it turns out, basic event segmentation skill seems to be present in the first year of life (Baldwin, Baird, Saylor, & Clark, 2001; Hespos, Grossman, & Saylor, 2010; Stahl, Romberg, Roseberry, Golinkoff, & Hirsh-PasekStahl, 2014), for at least some kinds of simple human action events. Having said this, it nevertheless also seems obvious that event processing, including segmentation skill, undergoes considerable reorganization developmentally, in part because knowledge seems to play such a central role in shaping it. A 12-month-old infant's understanding of a marriage ceremony, or of a presidential bill-signing event, for example, would have to be very different from that of an educated adult's, given their ignorance of the complex social and cultural foundations underlying such events. Infants might detect fine-grain units within the motion stream with some degree of fidelity (e.g., grasping a pen, bringing a pen to paper, making squiggles on the page with a pen) but lack an understanding of the higher order goals of the actors or what they signify within a larger event context. Hence, segmentation at higher levels and organization of event segments according to hierarchical, causal, and intention-goal structure probably change considerably as knowledge and development progress.

Our working hypothesis is that knowledge change and attentional reorganization in event processing are deeply interrelated in children's developmental progress. As children acquire new information about predictability relations in the world (knowledge) this will reshape their attention toward more efficient processing of the sensory flow. Progressively they will be able to selectively target junctures within unfolding experience at which relevant new information is predictably to be found (such as event boundaries, among other possibilities). As such reorganization occurs, event segments emerge as relatively stable entities in their experience, providing opportunity for noting similarities across events, which in turn enables children to construct event categories, learn labels (e.g., verbs) for them, and draw inferences about causal relationships that event categories enter into. Buchsbaum and colleagues recently documented portions of this developmental progression, demonstrating that both adults (Buchsbaum, Griffiths, Gopnik, & Baldwin, in press) and 3-year-olds (Buchsbaum, Gopnik, Griffiths, & Shafto, 2011) can use newly gained information (via statistical learning) about novel event segments to guide their causal inferences, and conversely, they can also use preexisting knowledge of causal structure to guide perception of event boundaries.

We are hopeful that the dwell-time paradigm will be a useful technique by which to further observe developmental change of just this kind as it is under way. One possible example here might be use of the dwell-time paradigm to observe developmental progress in conceptual-level knowledge, such as theory-of-mind understanding. To the extent that infants or young children either possess (e.g., Baillargeon, Scott, & He, 2010) or lack (e.g., Wellman, Cross, & Watson, 2001) lack an understanding of mentalistic concepts such as belief or knowledge, this will directly impact the predictions they have for how an event sequence will play out, which in turn will likely shape how they deploy their attention as the event proceeds. An older child or adult's understanding that an actor possesses crucial knowledge of a hidden threat, for example, might lead to enhanced dwelling on threat-relevant junctures within the unfolding stream of activity. In contrast, lacking an ability to appreciate the actor's knowledge state should leave infants and younger children oblivious to such threat-relevant junctures, with attendant differences in their dwell-time patterns. In collaboration with Jessica Kosie and Eric Olofson, research testing these and related predictions is currently under way.

Although knowledge seems to reshape event processing, which in turn yields developmental progress in event understanding, we suspect that individual differences in executive function are a key determinant of the pace of developmental progress in this arena. We (Dare Baldwin and Robbie Ross) are currently investigating the possibility of such links between individual differences in children's developing executive skill and fidelity of event processing. The preschool period is marked by rapid advances in executive system development. We predict that children in this age range will display variability in event segmentation patterns, as measured by dwell times, that is systematically related to their executive function skill. Moreover, we suspect that children with relatively poor executive skill will have difficulty reorganizing event processing in response to changing task demands. Findings from this research will help clarify whether developing executive skill impacts children's event-processing fluency, a finding with potentially wide-ranging implications for understanding individual differences in learning and cognitive growth.

CONCLUSION

We began with the cacophony of a cat-related catastrophe to illustrate that life presents itself to us as a multimodal flow of complex, dynamic information that we actively transform, or redescribe, into discrete, organized event structures. Our own and others' recent research begins to shed light on the nature of these redescription processes, and how they emerge in children's development. In brief, fluent event processing appears to involve skill at modulating attention to selectively capture predictable, structurally relevant, information-rich portions of an unfolding activity stream. Conceptualized this way, event-processing skill fundamentally depends on knowledge and executive skill. As knowledge of the world grows, more can be predicted. As more becomes predictable, it is increasingly possible to selectively project where, in the unfolding sensory flow, relevant new information is likely to be found (the predictably unpredictable). However, these developmental achievements likely depend critically on skill at flexibly reconfiguring attention based on knowledge and concurrent task demands, which requires a high-functioning executive system. Our hope is that gaining increased understanding of such relations among knowledge, executive skill, and event-processing fluency will ultimately enable us to enhance such fluency for all.

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