The association between real-world experiential diversity and event cognition

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Abstract

The ability to effectively parse our experience into meaningful events is thought to be critical for structuring episodic memory, engaging in daily activities, and navigating the social and spatial environment. Despite this, little is known about how inter-individual variation in this ability emerges. Within a sample of 159 young adults, we found that the degree to which individuals were exposed to a diverse range of social and spatial experiences (experiential diversity) was significantly related to event segmentation, such that individuals with greater daily variation in their social and spatial lives produced more fine-grained event segmentations during a movie-viewing task. Moreover, this effect remained when controlling for potential confounds, such as anxiety and loneliness. These results provide new insights into how real-world experiences may shape key memory encoding mechanisms, providing a potential cognitive pathway through which social disconnectedness impacts cognitive health and wellbeing.

Keywords: environmental enrichment; event cognition; episodic memory; social isolation

Introduction

While the world is in constant flux, we nonetheless experience our daily lives as a series of discrete events with beginnings and endings. This ability to carve experience into distinct chunks is thought to depend on the detection of event boundaries. Event segmentation theory proposes that these boundaries emerge from a prediction error signal elicited by shifts in either situational features (e.g., spatial location, people present) or internal states (e.g., arousal, goals)[1,2]. Once an error threshold is met, these boundaries trigger the generation of a new event model (a structured representation of an event within a specific spatiotemporal context) and the encoding of the

previous event model into long-term memory[3,4]. Prior work has shown that these boundaries can be readily measured by asking participants to watch a video and press a button whenever one natural and meaningful unit of activity ends and another begins[5]. Notably, the granularity at which people place event boundaries seems to be predictive of event memory[6], suggesting that event segmentation exerts an important influence on how events in long-term memory are organised and subsequently recalled. In line with this, event boundaries also seem to engage the same 'core' network of brain structures thought to support episodic remembering, including the hippocampus and posteromedial cortex[7–10].

Despite the importance of event perception for many aspects of our psychological lives (e.g., episodic memory, navigation, motor planning, social cognition)[11–14], there is a surprisingly limited understanding of how – and *why* – this ability differs across individuals, particularly within more naturalistic contexts. While previous work has emphasised high inter-subject agreement in where specific event boundaries are placed, considerable individual differences are nonetheless still observed[15]. This is perhaps unsurprising given that large individual differences in the granularity and detail of personal event memories are also readily seen, even within younger samples[16,17]. Given its intrinsic link to changes in the external world[2,4], a pertinent question is how event segmentation ability may be influenced directly by variability in day-to-day experiences. While many people around the globe exist within highly dynamic environments, offering considerable opportunity for experiential diversity, there are nonetheless clear differences in individuals' capacity to *exploit* this opportunity (e.g., due to isolation, loneliness, and poor physical and mental health)[18]. The goal of this study is to examine how such real-world experiential differences may influence the how events are perceived and encoded.

Support for a potential link between event cognition and experiential diversity comes from studies of environmental enrichment in animals, which suggest that enriched environments (which afford a diverse range of experiences and social interactions) lead to improvements in spatial-episodic memory, as well as neurogenesis in a network of brain structures linked to event cognition more broadly, such as the hippocampus and prefrontal cortex[19–21]. Similarly, in humans, low levels of *social* experiential diversity (which may be characterised by the number and frequency of social contacts) is associated with poorer memory performance in older adults[22,23], as well as increased risk of cognitive decline[24–26]. In the context of *environmental* experiential diversity, a recent study found that individuals who experienced more complex, irregular environments in childhood (e.g., rural areas or more 'organic' European cities) had improved spatial memory ability in later life[27]. At a shorter timescale, it has been found that regular exposure to a rich environment in the videogame Minecraft led to improvements in behavioural pattern separation, such that participants that were allowed to explore and create more complex and

expansive environments were better able to distinguish between old items and highly similar lures in a separate memory task[28]. While these studies do not provide evidence for a link between experiential diversity and event perception specifically, they nonetheless indicate that day-to-day variation in our experiences (such as large social networks and complex spatial environment) exerts a strong influence on the ability to form rich and distinct mnemonic representations, which may feasibly arise via key memory encoding mechanisms such as event segmentation[2].

To address this question, we examined the relationship between real-world experiential diversity and event segmentation ability, with the prediction that lower experiential diversity is associated with fewer event boundaries perceived during a naturalistic viewing paradigm. This prediction is not only based on evidence that experiential diversity has a detrimental effect on event memory and its underlying neural mechanisms (described above), but also reflects evidence that expertise within a particular domain (e.g., expertise in a particular sport) leads to more fine-grained segmentation of events within that domain[29], and may well reduce mnemonic interference (e.g., ref. [30]). To test this prediction, we collected a range of measures designed to assess various aspects of social and environmental diversity across a 30-day period, which together constituted our composite measure of experiential diversity (see Methods). By collecting data both on individuals' spatial and social environment, we were also able to examine the potential differential contribution of each form of diversity on event perception (see e.g., ref. [31]). Partial COVID-19 restrictions at the time of testing in the United Kingdom (https://www.gov.uk/government/publications/step-2-covid-19-restrictions-posters-12-april-2021) also provided a unique opportunity to study high inter-individual variability in experiential diversity within a young healthy sample of participants. In these same participants, we applied an event segmentation task, in which participants watched a short film and marked boundaries in their experience[8,9]. Critically, this film involves dynamic social interactions across multiple scenes and locations and is therefore ideal to examine the cognitive-perceptual consequences of social and spatial experiential diversity.

Methodology

Participants

All participants were recruited from the participant recruitment platform Prolific (https://prolific.ac) and reimbursed for their participation at a rate of £8.49/hr. Participants were between 18-35 years of age, UK residents, fluent English speakers and had no current or previous neurological or psychiatric conditions. Based on *a priori* power analysis, we aimed to collect a total of 153 complete datasets in a sample of young adult participants (which would provide 80% power to detect a one-tailed, small-to-moderate effect size of r = 0.2). A total of 177 participants

engaged with the study on Prolific, and 159 provided complete data for all variables of interest (mean age = 26.4; SD = 5.3; range = 18-35; 92 females, 65 males, 1 trans demi-boy, and 1 non-binary). This study was approved by the Royal Holloway Department of Psychology Research Ethics Committee (ethical approval reference 2171).

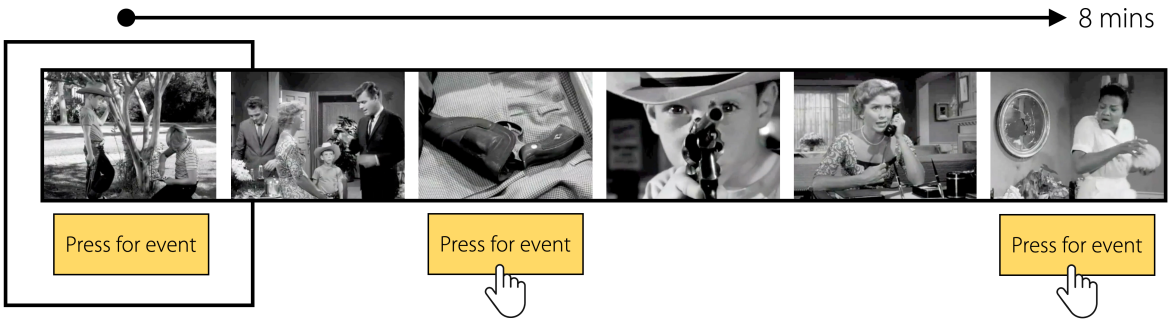

Figure 1. The event segmentation task. The event segmentation task involved the presentation of the 8-minute movie "Bang! You're Dead". The movie was shown above an on-screen button, which participants could press to mark meaningful events that they perceived.

Procedure and materials

Participants from Prolific were directed to Qualtrics (www.qualtrics.com) to complete the experiment. The paradigm was optimised for computers, phones, and tablets.

Event segmentation task

We used an event segmentation task that has been applied in recent functional MRI studies of event perception[8,9]. Here, participants watched an abridged version of Alfred Hitchcock's black-and-white television drama "Bang! You're Dead"[32]. This film was chosen as it is highly suspenseful, but also involves several social interactions across multiple scenes. This contrasts with many other studies of event segmentation that have mainly used videos depicting a single agent performing action sequences or daily activities[5,14,33]. Importantly, also, no participant reported seeing this film before, meaning that perceived events were not driven by prior knowledge of the film itself. During the movie, participants were required to press an on-screen button (using their mouse or phone/tablet touchscreen) whenever they judged one event to end and another to begin (Figure 1). They were instructed that there were "no right answers in this task" and to just respond in a way that feels natural to them. The main measure of event segmentation was the total number of perceived event boundaries per participant (i.e., the total number of button presses during the movie; e.g., refs [29,34]).

Experiential diversity

The experiential diversity measure was designed to capture the diversity of each participant's 'social' and 'spatial' experiences over the preceding 30 days. The *social experiential diversity* score was comprised of two sub-scales. The first included several questions which assessed the regularity and format of recent social interactions (see Supplementary Information, Appendix A), and scores could range from 0-6. The second sub-scale was a measure of social network size, adapted from previous studies of social cognition[35,36]. For this, participants were asked to write the initials of every individual with whom they had had meaningful social contact or communication over the last 30 days. This questionnaire is thought to probe the second layer of an individual's social network (the 'sympathy group'; see ref. [37]), and the 30-day limit is thought to maximise variation across individuals while also minimising the time and effort required to complete the questionnaire. The social experiential diversity score was a composite of these sub-scales and ranged from 3-50 (mean = 15.9, SD = 8). The *spatial experiential diversity* questionnaire was designed to assess the complexity of each participant's immediate environment, including the number of rooms number they spend their time in on a typical day, access to private outdoor space, and the frequency in which they explore their local neighbourhood (see Supplementary Material, Appendix B). Scores on this measure could range from 0–16 (mean = 7.9, SD = 3, range in sample = 0-13). Scores on the social and spatial measures were combined into an overall experiential diversity score (mean = 23.8, SD = 9.3, range = 5-60).

Other questionnaires

In addition to our main measures above, we also collected data on several covariates of interest. The first of these was The Campaign to End Loneliness Measurement tool[38], which is a 3-item tool to assess subjective feelings of loneliness. The three items on this tool are: *"1. I am content with my friendships and relationships"; "2. I have enough people I feel comfortable asking for help at any time"; "3. My relationships are as satisfying as I would want them to be"*. Participants could respond to each statement on a 5-point scale: 'Strongly disagree' (coded as 4 points), 'Disagree' (coded as 3 points), 'Neutral' (coded as 2 points), 'Agree' (coded as 1 point), and 'Strongly agree' (coded as 0 points). This coding scheme produces scores ranging from 0-12, where higher scores indicate higher levels of subjective loneliness. To control for general feelings of anxiety (see Results), participants also completed the trait component of the State-Trait Anxiety Inventory (STAI-T)[39]. The STAI-T contains 20 items assessing the frequency of anxiety generally felt by participants, and participants respond on a four-point scale from 'Almost' to 'Almost Always'. Scores can range from 20-80 with high scores indicating high levels of general anxiety.

Statistical analysis

All statistical analyses were conducted using R (version 4.0.2; R Core Team, 2019) in RStudio (version 1.4.1106; RStudio Team, 2021). Key correlational analyses (e.g., between total experiential diversity and event segmentation frequency) were conducted using two-tailed bivariate correlations, with the contribution of potential covariates explored using partial correlations and multiple regression analyses (see Results). Partial correlations were carried out using the 'ppcor' [40] package in R. Comparisons between correlation coefficients were performed using Steiger Z-tests (Steiger, 1980) within the 'cocor' package in R[41].

Results

Experiential diversity is strongly correlated with event segmentation

We predicted that experiential diversity would be positively associated with event segmentation ability, such that individuals who report greater variation in their spatial and social world would show more fine-grained event boundary segmentation. Initially, a bivariate Pearson's correlation was conducted between total experiential diversity and the number of event boundaries perceived (see Methods). Consistent with our predictions, we observed a significant positive correlation between experiential diversity and event segmentation frequency ($r(157) = 0.27$, $p = 0.0006$; Figure 2).

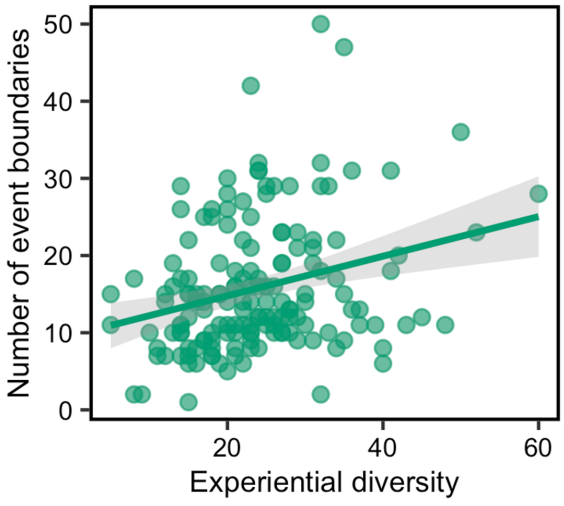

Figure 2. The relationship between total experiential diversity and the number event boundaries perceived. Each data point reflects an individual participant and there are 159 data points shown on the plot. The shaded area represents the 95% confidence interval on the best-fitting regression line.

Controlling for anxiety and loneliness

One possible explanation for this finding is that individuals with smaller social support networks, or with limited access to diverse spatial environments, display greater anxiety, as well as loneliness. Systematic biases in event memory, such as a propensity to recall more extended generalised events, may be a hallmark of mood disorders[42–44]. As such, it is possible that such memory biases also drive variation in how events are initially perceived and encoded. To test for this, we conducted a multiple regression with event segmentation as the outcome measure and experiential diversity, anxiety, and loneliness as the predictors. The effect between experiential diversity and event segmentation was found to hold when controlling for both anxiety and loneliness ($\beta = 0.25$, $p = 0.0007$). Notably, there were also no independent relationships between event segmentation ability and either anxiety ($p = 0.09$) or loneliness ($p = 0.17$), suggesting that this effect is not driven by the subjective 'quality' of individuals' social interactions, or anxiety linked to isolation, but rather by the objective diversity of these experiences.

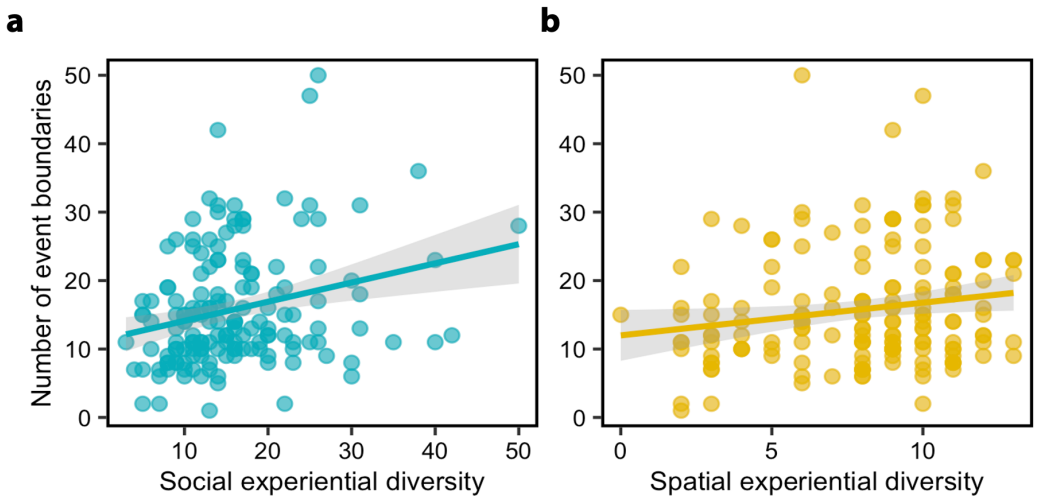

Figure 3. The relationship between social and spatial experiential diversity and event segmentation. Each data point reflects an individual participant and there are 159 data points shown on the plot. The shaded areas represent the 95% confidence interval on the best-fitting regression line.

The differential contribution of 'social' and 'spatial' experiential diversity

We next examined the relative contribution of social and spatial experiential diversity measures to event segmentation. While both sub-measures are significantly associated with experiential diversity (at $p = 0.05$), the effect is stronger numerically for *social* ($r(157) = 0.25$, $p = 0.001$; Figure 2)

relative to *spatial* (r (157) = 0.17, p = 0.03; Figure 2) experiential diversity – though these correlations do not differ significantly (z = 0.96, p-value = 0.34). A separate question is whether social or spatial components of experiential diversity make independent contributions to event segmentation. Indeed, when spatial experiential diversity is controlled for within in a multiple regression model, social experiential diversity still significantly accounts for the variation in event boundary perception (β = 0.24, p = 0.006). Overall, these results suggest that social experiential diversity is main contributor to event perceptual ability in this study.

Discussion

In the current study, we examined whether inter-individual differences in experiential diversity is associated with inter-individual variation in the ability to perceive events in ongoing experience. To assess this, we related event segmentation (the number of perceived event boundaries) during a naturalistic movie stimulus to measures of both social and spatial experiential diversity, such as the frequency and quality of social interactions, and the capacity to explore the immediate spatial environment (e.g., household, local neighbourhood). Our results yielded several key findings in relation to this question. First, we found that experiential diversity was strongly related to how many event boundaries were perceived during the movie viewing task, such that participants who had recent exposure to a wider range of social and spatial experiences provided more fine-grained segmentations of events as they unfolded. Second, we found that this effect held when controlling for anxiety and loneliness, addressing the possibility that this effect reflects variation in mood/anxiety linked to isolation. Thirdly, when comparing social and spatial aspects of experiential diversity, we found that social context accounted for more of the variation in event perception (though these correlations did not significantly differ from one another when compared directly).

The key question for the current study is what are the cognitive and/or neural mechanisms underlying this relationship. One possibility is that experiential diversity influences event perception by altering the functional 'integrity' of a core network in the brain, which is has been implicated in both event perception[7,9,45] and memory[46,47]. As briefly outlined in the Introduction, previous studies suggest that social and environmental enrichment may influence memory via functional changes in the hippocampus and interconnected structures[48,49]. For example, isolated mice show marked decline in spatial memory when compared to those housed in groups, and this is associated with a host of micro- and macro-structural changes in the hippocampus and prefrontal cortex (e.g., demyelination, neuroinflammation and synaptic protein loss)[50,51]. Notably, these changes in cognitive and neural markers may also be mitigated by exposure to complex and enriched spatial environments[52]. Similarly, re-socialization of previously isolated mice has been

shown to reverse the negative consequences of social isolation on hippocampal plasticity[53]. These laboratory studies in nonhuman species underline the intimate relationship between *immediate* social and spatial experience and the structural-functional integrity of the brain's event memory system[24,31,54,55].

In human participants, it has been shown that reduced social contact impairs memory in older adults[23], and has been shown to increase risk of developing Alzheimer's disease[25]. In particular, it has been suggested that social isolation may act as a stressor which impacts primarily the extended hippocampal memory system, leading to pathophysiological changes that lead to memory decline and Alzheimer's disease[56]. While very few studies have examined the influence of low experiential diversity on brain structure and function in humans, those conducted have found that regions implicated in event memory and social cognition (such as hippocampus, parahippocampal cortex, and amygdala) may be most susceptible to isolation and loneliness[57]. For instance, one particular study found that individuals who underwent sudden and prolonged isolation (polar expeditioners) showed lower hippocampal volumes when compared to matched controls[58]. Focusing more directly on spatial aspects of experiential diversity, a recent study by found that individuals who engaged in more complex exploratory behaviour in their local neighbourhood (i.e., as measured by the metric 'roaming entropy') were found to have increased positive affect, and this relationship itself was linked to hippocampal-striatal connectivity[18].

While many studies point towards reductions in key brain structural measures (e.g., grey matter volume), a recent large-scale study in middle-to-old aged adults found that enduring feelings of isolation (i.e., 'trait' loneliness) were associated with increased structural connectivity in the fornix – a prominent white matter tract that links the hippocampus/subiculum and prefrontal cortex[59]. Rooted in the potential role of this pathway in episodic memory and simulation[60], this enhanced connectivity in lonely individuals may reflect a heightened focus on internally-generated thoughts (e.g., socially-themed episodic memories and simulations)[61]. It is possible, therefore, that increases in both social and non-social imagination (arising from reduced levels of experiential diversity) may well consume resources within the event memory system and impair participants' ability to effectively monitor shifts in events as they unfold[59]. Another possible interpretation of these findings is that high experiential diversity influences event segmentation in a similar manner to that seen in expertise, such that individuals with high social or spatial experiential diversity can use their recent knowledge within those domains to guide segmentation (e.g., via top-down attentional mechanisms). For example, in a recent study, basketball experts were found to produce more event boundaries compared to novices when watching basketball games, particularly when asked to focus on fine-level events[29] (but see ref. [62]). In the current investigation, therefore, it may be that participants' segmentations align at the coarse-level (e.g.,

for large scene changes, or major plot points) but that individuals with greater experiential diversity had increased sensitivity to finer-scale, sub-events linked to subtle changes in spatial and/or social cues. Due to how this experiment was administered, we were unable to determine *when* boundaries were placed, and so cannot ascertain which situational features were most salient for individual subjects[6]. For example, it may be the case that the correlation between social experiential diversity and overall event segmentation reflected predominantly variation in participants' ability to attend to, and process, social versus non-social features of events (e.g., character interactions, facial expressions, character intentions)[11].

Previous studies have also found that lonely individuals have enhanced vigilance to negative social information[63], suggesting that lower social experiential diversity could, in specific contexts, result in enhanced sensitivity to negative events or sub-events. It is, however, important to state that loneliness itself did not relate to event segmentation in the current study, and in fact the relationship between experiential diversity and segmentation ability held when controlling for loneliness. This is important as it implies that reduced social contact may be sufficient to impose real-world psychological costs – even without associated feelings of loneliness.

While prior studies have suggested high inter-subject agreement to be a hallmark of event segmentation[64], the current study demonstrates that there are nonetheless considerable individual differences in how events are perceived, particularly regarding the granularity of event boundary placement – even in young adults. The observation of large individual differences is not wholly unsurprising given known individual variation in how people retrieve real-world events[16,17]. One explanation for the higher inter-individual variation seen here is the actual stimulus used. While many classic studies of event boundary segmentation have focused on basic action sequences with a single agent[6], we instead opted for a richer stimulus, which involves the dynamic tracking of location and character, as well as their intentions and emotions across scenes. As such, this stimulus may be more amenable to detecting individual differences aligned to experiential factors.

We must also highlight that this study was conducted as COVID-19 restrictions were being slowly relaxed in the United Kingdom (https://www.gov.uk/government/publications/step-2-covid-19-restrictions-posters-12-april-2021), meaning that many children and adults had undergone a prolonged and acute phase of isolation. As such, individuals who scored low on our measure of experiential diversity (covering 30 days prior to test) may well have undergone a sustained and profound period of low experiential diversity, and potentially social isolation. Given the well-established relationship between stress and memory function[65,66], it may well be the case that the effects in the current study are stronger than would be typically observed in a sample of this type due to prolonged exposure to environmental stressors (e.g., perceived lack of safety and

social isolation). While this does not necessarily alter the mechanistic interpretation (e.g., short-term alterations in specific brain networks or top-down attentional processes; see ref. [67]), it will be important to conduct future longitudinal studies to gain further insight into the time course and 'dose' dependence of these effects.

Conclusion

As well as potentially underpinning how memories are encoded and ultimately organised in long-term memory, the ability to effectively parse conscious experience into meaningful chunks may be central to how we effectively engage in daily activities[13] and navigate complex social environments[11]. Despite this, relatively little is known about how inter-individual variation in this ability emerges. In the current study, we found that the degree to which individuals are exposed to a diverse range of social and spatial experiences (experiential diversity) was strongly related to event segmentation ability during a naturalistic move viewing paradigm. Moreover, this effect was maintained when controlling for potential confounds, such as anxiety and loneliness. By demonstrating a link between experiential diversity and a key event encoding mechanism (event boundary segmentation), this study provides new insights into how individual differences in social and environmental disconnectedness might influence real-world memory. Future work should focus on better understanding how experiential diversity shapes encoding of different forms of event-related information (e.g., social vs. non-social information) across the lifespan, as well as how everyday memories are recalled and subjectively re-experienced.

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CRediT author statement

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