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Understanding the structure of autobiographical memories: A study of trauma memories from the 1994 Rwandan genocide

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Abstract
How do we remember traumatic events, and are these memories different in individuals who experience post-traumatic stress? Some evidence suggests that traumatic events are mnemonically enhanced, or include more episodic detail, relative to other types of memories. Simultaneously, individuals with post-traumatic stress disorder (PTSD) have more non-episodic details in all of their memories, a pattern hypothesized to result from impairment in executive function. Here, we explore these questions in a unique population that experienced severely traumatic events more than 20 years ago – individuals who lived through the 1994 genocide in Rwanda. Participants recalled events from the genocide, negative events unrelated to the genocide, neutral events, and positive events. We used the Autobiographical Interview method to label memory details as episodic or non-episodic. We found that memories from the genocide showed robust mnemonic enhancement, with more episodic than non-episodic details, and contained more details overall than any other memory type. This pattern was not impacted by post-traumatic stress. Overall, this study provides evidence that traumatic events create vivid long-lasting episodic memories, in this case even more than 20 years later.

Keywords Autobiographical memory · Rwandan genocide · Trauma · Episodic memory

Introduction

Autobiographical memory (AM) encompasses both our general and semantic knowledge about ourselves (e.g., our first name) and memories of events in our lives (e.g., the evening of our high school graduation). These events can range from the mundane, like shopping for groceries, to more emotionally charged events, like the birth of a child. In some cases, events occur that are considered traumatic. A traumatic event is defined as involving actual or threat of death, serious injury, or loss of physical integrity of the self or others (DSM V American Psychiatric Association, 2013). These events typically evoke intense feelings of fear and helplessness, and for some individuals can lead to post-traumatic stress disorder (PTSD) (Breslau, 2009).

A major open question is why do some individuals but not others develop PTSD. According to the mnemonic model of PTSD, it is not the event per se, but the nature of the event memory that determines PTSD symptoms (Rubin et al., 2008b). How are traumatic events remembered, and how are they different in individuals with PTSD? Clinical observations and prominent theories have emphasized that trauma memories are often distorted or fragmented (Brewin, 2014; Brewin et al., 2010), or even difficult or impossible to remember (dissociative amnesia) (Brewin & Holmes, 2003; Dalgleish & Power, 2004). In fact, inability to remember central details of the event was a diagnostic criterion in the DSM-IV (American Psychiatric Association, 2000). At the same time, a number of studies find evidence that memories of traumatic events are recalled frequently (including voluntarily), vividly, and in a highly detailed manner, in individuals both with and without PTSD (Bernsten et al., 2003; Bernsten & Rubin, 2014; Gray & Lombardo, 2001; Rubin et al., 2008a, 2008b, 2011; Porter & Birt, 2001). Also, PTSD

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symptoms have been associated with *overgeneral* or less specific and detailed autobiographical memory, across all memory types, potentially related to alterations in executive function or general cognitive abilities (Brown et al., 2013; Dalgleish et al., 2007; Gray & Lombardo, 2001; McKinnon et al., 2015). Thus, the relationship between memories for traumatic and non-traumatic events, PTSD, and executive function requires further exploration.

One powerful approach for probing the structure of real-life traumatic and non-traumatic memories is the autobiographical interview (AI) developed by Levine et al. (2002). This semi-structured interview requires participants to recall events in as much detail as possible. Verbal event recall is then transcribed verbatim, and details within the event are coded into two main categories: internal details and external details. For simplicity, we will refer to internal details as *episodic details*, and external details as *non-episodic details*. Episodic details are related to the main event described, and specific in time and place for that event. In addition to event details (who, what, how), this category includes details about the spatial, temporal, or perceptual information linked to the event, as well as the emotions and thoughts an individual was having at the time of the event. Episodic details are associated with subjective re-experiencing of the event during recall, or what Tulving referred to as "mental time travel" (Tulving, 1972). Non-episodic details include details in the narrative not related to the main event, nor specific in time and place, and include semantic details (personal or general facts), external event details, repetitions, or other (e.g., metacognitive statements). The number or proportion of episodic details in a memory can be used as a quantitative measure of memory quality, providing a tool to understand how memory is shaped by different events and pathologies.

Using this approach, McKinnon et al. (2015) studied participant memories of a near fatal plane crash. Following a mechanical malfunction, air Transat flight AT236 nearly crashed in the Atlantic Ocean in August 2001. Thankfully, the captain was able to make an emergency landing in the Azores, and no passengers were seriously injured. In their study, former passengers recalled their experience of this event as well as a neutral life event from the same time period, and another highly negative event for which they were not personally involved – September 11 2001. Memories of the traumatic event were robustly enhanced. Specifically, memories from the flight had more episodic details than non-episodic details, and more episodic details than other memories, and this enhancement was seen in all individuals, regardless of whether they developed PTSD or not following the event. In this study researchers also examined accuracy, measured as the proportion of verifiable event details present in memories, and found no evidence for differences between individuals who had PTSD and those who did not. In general, these results support the idea that traumatic events are mnemonically enhanced, even in individuals suffering from PTSD.

Interestingly, the main difference in the memories of individuals with PTSD in the air Transat study was that they included more non-episodic details, and this was the case across all memory types and not just memories of the flight. This pattern, an elevation of non-episodic details in memory recall with PTSD, has also been reported in US combat veterans (Brown et al., 2013). Veterans with PTSD compared to those without also had less episodic details in their memories, and this pattern of elevated non-episodic and decreased episodic details extended into future imagined scenarios. Importantly, in this study participants were cued to recall memories using neutral words, so there was no examination of trauma memories. One possibility is that this pattern in memory recall is due to impairments in executive function known to be common in PTSD (Aupperle et al., 2012). Indeed, executive functions, in particular cognitive flexibility, play an important role in monitoring the content of memory recall (for a review, see Diamond & Levine, 2018). For example, individuals with frontal lobe damage and concurrent executive dysfunction produce memories that are higher in non-episodic details (McKinnon et al., 2008). However, there is little direct evidence testing whether this accounts for increased non-episodic details in PTSD memories. There were no measures of executive function included in the AT236 study. Brown et al. (2013) included a measure of semantic fluency, considered to be a measure of cognitive flexibility (Diamond, 2013), but found no relationship between fluency, memory details and PTSD – nor fluency and memory details more generally.

In sum, the nature of trauma memories, if and how these memories differ in PTSD, and the relationship between memory recall and executive function remains to be fully understood. So far, evidence from probing the structure of trauma memories shows these memories are specific, high in episodic detail, and accurate, even in individuals with PTSD. Simultaneously, all types of memories in individuals with PTSD include more non-episodic details, suggesting a general alteration in AM. Whether this increase in non-episodic details is related to an impairment in executive function, and in particular cognitive flexibility, remains unclear. To our knowledge, these are the only two studies using this method to examine the structure of memory recall in PTSD, and only the McKinnon et al. (2015) study examines trauma memories from the event that caused PTSD. Further, trauma memories in McKinnon et al. study were examined approximately 3.5 years following the event. Whether mnemonic enhancement to trauma memories is long-lasting, or memories become disrupted over longer time periods, particularly in the case of long-lasting PTSD, has not been examined.

To address these open questions, we examine memories for traumatic events that occurred more than 20 years ago,

from individuals who lived through the 1994 genocide in Rwanda. The genocide, perpetrated against the Tutsi, led to the death of almost 1 million people in just 100 days. Rwanda is a small densely populated country, meaning that all Rwandans present in 1994 were exposed to extremely traumatic events. Indeed, even 15 years later, a nationally representative sample estimated that as much as 26% of the population suffers from post-traumatic stress symptoms (Munyandamutsa et al., 2012). In this study, our primary goal was to understand the structure of individuals' memories of the events that occurred during the genocide. Specifically, we hypothesized that even after more than 20 years, these memories would be mnemonically enhanced relative to memories of other life events. To examine this, participants were cued to recall memories from the genocide, as well as memories of neutral, or positive life events, because participants sometimes generated negative life events in response to the neutral cue, we subdivided our data into four categories: negative genocide, negative non-genocide, positive, and neutral memories. We used the Autobiographical Interview (AI) method (Levine et al., 2002) to label event details as episodic or non-episodic. We predicted that memories from the genocide would be higher in episodic detail, similar to the enhancement of episodic detail reported in the recall of a life-threatening event in the near plane crash study (McKinnon et al., 2015). In addition, we examined the relationship between memory recall and post-traumatic stress symptoms (PTS), we hypothesized that increased PTS would be associated with increased non-episodic details, across all memory types, as has been found in two previous studies (Brown et al., 2013; McKinnon et al., 2015). Last, we examined the general relationship between cognitive flexibility and memory detail generation during recall, and its relationship to PTS symptoms.

Methods

Participants

Autobiographical memories were collected as part of a larger study on the relationship between trauma exposure and cognition in individuals who lived through the 1994 genocide in Rwanda. To participate in the study, our criteria were that individuals had to be at least 10 years old at the time of the genocide, have been present in Rwanda during the genocide, and be able to speak and read in Kinyarwanda. Reading in Kinyarwanda was necessary to complete a number of other tasks and questionnaires in the session on the computer (outside of the memory interview). Data were collected during two 3-week research visits, in February and August 2016, participants were recruited by word of mouth, and as many participants as possible were recruited during the 3-week testing window. Sessions took place across four rural and urban sites: Kigali, Ntarabana, Muyumubu, and Butare. The session lasted approximately 90–120 min and included a number of cognitive tasks and questionnaires performed independently on the computer. Tasks included measures of cognition, specifically, an Nback, Raven's progressive matrices, forward and backward digit span, a verbal (semantic) fluency task, and a reading fluency task. Questionnaires included the post traumatic symptoms checklist – civilian (PCL), the Hamilton Depression Rating Scale, impact of genocide Questionnaire, and a demographics questionnaire. Results using these measures to probe the relationship between trauma and cognition have been previously published (Blanchette et al., 2019; Caparos et al., 2018, 2020; Giroux et al., 2020). After participants finished the computer-based part of the session, if there was still enough time and they chose to, they were invited to participate in the Autobiographical Interview. In total, participants were 110 (58 female and 52 male) individuals who lived through the 1994 genocide in Rwanda. Participants were between the ages of 29 and 64 years ($M = 35.84$, $Median = 33$). Twenty-seven percent of participants had a university education, 34% a secondary education, 32% primary school, and 7% had no formal education. Note that while the criterion was to be at least 10 years old, participants age was recorded at the start of the larger study, and not re-examined prior to the memory interview, yielding a number of participants aged 7–9 years at the time of the Genocide. Participants were read a letter of information at the start of the study and signed a written consent. They were compensated 8,000 RWF, equivalent to approximately $15 CAD at the time of the study, for their transport costs and participation time.

Post-traumatic stress symptoms

Participants completed the Post Traumatic Symptoms Checklist – Civilian (PCL-C), which was translated into Kinyarwanda (Blanchard et al., 1996). This questionnaire measured current symptoms of post-traumatic stress from the genocide. Participants rated items on a scale of 1 (not at all) to 5 (extremely). Items addressed symptoms from three clusters intrusions (i.e., persistently remembering or reliving the genocide through intrusive flashbacks, vivid memories, and/or recurring dreams), avoidance/numbing (i.e., efforts to avoid any circumstance resembling or associated with the genocide; feelings of detachment or emotional numbness), and hyperarousal (difficulty falling or staying asleep, irritability or outbursts of anger, difficulty concentrating, hypervigilance, exaggerated start response).

Cognitive flexibility measure

Participants completed a semantic verbal fluency task, which is thought to be a good measure of high-order executive function, in particular cognitive flexibility (Diamond, 2013). In the current study, we asked whether performance on this task related to autobiographical memory recall.

Semantic fluency

Participants were given 1 min to name as many items as they could for three separate categories: animals, first names, and countries. Participants could choose their preferred language for the task (Kinyarwanda, French, or English). The total number of correct items (excluding repetitions or items from a different category) named in all three categories was the outcome measure, and a z-score was taken and used in all subsequent analyses.

Autobiographical memory task

Memory interviews were conducted by a researcher from our team in conjunction with a local research assistant who spoke Kinyarwanda and was a trained clinical psychologist in Rwanda. Participants could choose to do the interview in Kinyarwanda, French, or English (or switch languages at any time) and interviews were audio-recorded. The majority (72%) of participants chose to do the interview in Kinyarwanda, in which case the research assistant translated the instructions and back translated the participants memories to the experimenter in real time. Interviews took place in small, isolated rooms to preserve confidentiality, and the experimenter explained that recordings would remain anonymous and only be used by the research team. Oral consent was obtained before starting the interview and recording (in addition to written consent obtained at the start of participation in the larger study). The interview protocol was based on the Autobiographical Memory Test (AMT), which provides valanced cue words to elicit autobiographical memories, and has been widely used to study the impact of depression and PTSD on autobiographical memory specificity (William & Broadbent, 1986; Williams et al., 2007). While this method emphasizes generation of a specific event, in our protocol participants were encouraged to generate a specific event, and to elaborate on that event (i.e., describe their memory of the event in as much detail as possible). Specifically, participants started with a practice trial, they were given the neutral cue word "market" and instructed that they should use the word to come up with a specific memory, something that happened to them personally, and occurred on a specific day in a specific place, and they should then describe that memory in detail to the interviewers. Once the participant came up with and described a specific memory, the experimenter told them that was exactly what they needed to do on the next trials, when presented with other word cues. If they didn't come up with a specific practice memory, the experimenter guided them by repeating the instructions and asking follow-up questions until they were able to report a specific memory, after which the experimental trials began. Experimental trials started with a neutral cue word ("mountain" or "bus"), participants were then asked, if they were comfortable, to share a specific memory elicited by the cue word "genocide," finally they were asked to retrieve a memory using the cue-word "joy" to finish the session. The order the cue words were presented in did not change in order to end on a positive cue for emotional regulation. If participants' spontaneous response was very brief or general, they were prompted one time by the experimenter, who asked "can you tell me more." Data collection initially began with the cue word "mountain," which was intended to be neutral, but experimenters noticed that for many participants "mountain" elicited negative memories from the genocide, as many people lived in or fled to and hid in the mountainous in the north-west region of Rwanda during the genocide. Experimenters thus switched to "bus" in the hopes to elicit predominantly neutral memories.

Ethics

Conducting a study on genocide exposure in Rwanda requires serious ethical considerations. In addition to approval by the ethics board at Université du Québec à Trois-Rivières in Canada, this study was reviewed and approved by the National Ethics Committee in Rwanda, the National Unity and Reconciliation Commission, and the National Commission for the Fight Against Genocide. Permission was required from all three authorities to conduct this study. Continuous close discussions were held on how to minimize risks for participants throughout the project. At the end of the session participants were invited to ask questions, express their views on the study, and were asked how they were feeling. The majority of participants were extremely positive about their experience. The experimenters took the time to listen to their experiences and help them regulate any negative emotions that arose. Participants were invited to contact the experimenters if negative feelings remained or returned at a later time in relation to the experience.

Coding autobiographical memories

Memories were transcribed verbatim, in order to use the AI coding method (Levine et al., 2002; Wardell et al., 2021a) to categorize details in the memory narrative into episodic or non-episodic details. The episodic category included: event details, place details, time details, perceptual details, and emotion/thought details, while the non-episodic category

included: general semantic details, personal semantic details, self-knowledge, external specific events, repeated events, extended events, repetitions, and other (following the coding schema for non-episodic details recommended in Renoult et al., 2020). Memories narrated in English or French were transcribed by English-French bilingual research assistants on our team. Kinyarwanda memories were translated to English and transcribed by a professional, who also worked closely with the research team to provide cultural context, for example if a certain concept was not directly translatable. Transcriptions were then coded by two research assistants, who completed a training module supplied by the Levine et al. laboratory. The training module consisted of a set of 20 example memories. Research assistants coded a set of ten example memories, calculated correlations for episodic, non-episodic, and total detail counts with the four expert coders (supplied in the module). If the mean correlation for each detail type was 90% or higher, they moved on to the Rwanda data, if not, they evaluated discrepancies, discussed them with the first author, and then coded the next set of ten example memories. Once all research assistants reached 90% for each category on the training module, they began coding memories from the Rwanda dataset. The first five memories in the Rwanda dataset were also coded by the first author and two other lab members. Mean correlations across all raters were 97% for total details, 95% for episodic details, and 95% for non-episodic details. Both research assistants had a mean correlation on all three categories of details (episodic, non-episodic, and total) above 90%. Following this, all remaining memories were coded. Coders first decided whether there was an event that was possible to score in the response for each cue. Following the AI instructions for older memories, coders considered events that could have unfolded within ~2 days to be considered a single event, and also closely adhered to the instructions for very impoverished events, which states that the coder should be inclusive and select some details as *probably* specific to an event and scored them. If this was not possible, the narrative from that cue word was excluded. When examining memory transcriptions, we realized that cue words did not always elicit the intended memory content. For example, neutral cue words sometimes elicited negative memories, sometimes from the genocide (i.e., "mountain" evoking a memory of hiding in the mountains during the genocide), and sometimes from other negative events outside of the genocide ("bus" evoking a memory of witnessing a bus crash). In order to most accurately analyze genocide memories compared to non-genocide memories, and memories of different valence, coders provided a rating for each memory based on perceived overall valence: negative, positive, or neutral, and whether or not the event occurred during the genocide or not. This resulted in four conditions: genocide memories, negative non-genocide memories, positive memories, and neutral memories.

Analyzing autobiographical memories

All data analyses were done using linear mixed effects modeling with the *lme4* package (version 1.1-31; Bates et al., 2015) in R (version 4.2.3). We elected to use mixed models, as opposed to an ANOVA, in order to include as much data as possible, given that not all participants generated a memory for each of the four conditions (for a full discussion of the benefits of a mixed model approach, see Brown, 2021, or Baayen et al., 2008). We used Brown (2021) as a guide to implementation and best practices. We created three models to explore three questions. Each model included participant as a random effect. For the first model, we focused on our primary research question "Are memories from the genocide recalled differently from other memories." To test this, we used the total number of details generated as the dependent variable, and compared the two broad categories of details, episodic and non-episodic. Specifically, we asked whether a model predicting an interaction between detail type (episodic or non-episodic) and memory type (negative non-genocide, genocide, neutral, or positive) (model 1) better fit the data than a model without memory type (null model). In models 2 and 3, we asked, "Does cognitive flexibility (measured by semantic fluency) influence memory recall?" and "Do post-traumatic stress symptoms impact memory recall?" We used the number of details as the dependent variable and compared a model including an interaction between detail type (episodic or non-episodic) and semantic fluency (model 2) or detail type (episodic or non-episodic) and PCL-C score (model 3) to one with only detail type (null model). To test which model was a better fit, we performed an ANOVA comparing the two models. If our test model was significant, we explored the results using the summary function, and completed post hoc tests and visualizations using the *emmeans* package (version 1.8.6), with the *Interaction Analyses* in emmeans vignette as a guide to implementation and best practices. We used the Tukey method of correction for multiple comparisons for post hoc tests, which is the default setting in the emmeans function for pairwise comparisons.

```
null model <- lmer(#details ~ detail type +(1|Participant), dataframe)
model 1 <- lmer(#details ~ detail type *memory type +(1|Participant), dataframe)
model 2 <- lmer(#details ~ detail type *ZscoreFluency +(1|Participant), dataframe)
model 3 <- lmer(#details ~ detail type *PTSD symptoms +(1|Participant), dataframe)
```

Results

Are memories of the genocide recalled differently from other memories?

The model including memory type (model 1) was a better fit for the data than the model with detail type alone (null model) ($\chi^2(6) = 31.574$, $p < .0001$). There was a main effect of detail type (t(402) = 3.366, $p < .0001$, *SE* = 0.826), a main effect of memory type (t(402) = 2.361, $p = 0.0186$, *SE* =0.728), and an interaction between detail type and memory type (t(402) = - 2.52, $p = .0249$, *SE* = 1.330), between negative non-genocide memories and neutral memories. Overall, memories were composed of more episodic than non-episodic details (β^ = 2.78). Post hoc contrasts examining the difference (non-episodic – episodic) revealed that this was significant in both genocide (β^ = - 2.827, *SE* = 0.563, $p = <.001$) and negative non-genocide memories (β^ = - 2.780, *SE* = 0.826, $p = 0.0008$), positive memories followed the same pattern but the difference was not significant (β^ = - 1.903, *SE* = 1.139, $p = 0.0956$), whereas neutral memories clearly showed no differences (β^ = 0.216, *SE* = 1.043, $p = 0.8359$) (Fig. 1). Memories from the genocide were more detailed than any of the other types of memories recalled (Online Supplementary Material Fig. 1; genocide: *Mean details* = 9.5 , *SD = 0.436, range = 1–45*; Negative non-genocide: *Mean details* = 6.02 , *SD = 0.627, range = 1–19;* Neutral: *Mean details* = 4.17 , *SD = 0.796, range = 1–12;* Positive: *Mean details* = 6.2 , *SD = 0.864, range = 1–47*); notably, this effect was significant even when comparing genocide memories to non-genocide negative memories (β^ = 1.726, *SE* = 0.7716, *p = 0.026*). To evaluate whether the differences between genocide and negative non-genocide memories were driven by outliers, we excluded datapoints greater than 3 standard deviations above the mean for total number of details produced. Post hoc contrasts revealed that even with this more conservative analysis, genocide memories were still significantly more detailed overall than negative non-genocide memories (β^ = - 1.674, *SE* = 0.557, $p = 0.0160$)**.** To further understand this effect, we modeled the number of episodic details and the number of non-episodic details separately and examined the impact of memory type (relative to a model without memory type) (episodic model and non-episodic model). Models including memory type better fit the data for episodic details ($\chi^2(3) = 18.882$, $p = 0.0002892$) and non-episodic details ($\chi^2(3) = 10.427$, $p = 0.01527$). Post hoc contrast tests showed that genocide memories had significantly more episodic details compared to neutral memories (t(238) = 3.995, β^ = 4.098, *SE* = 1.026, *p = 0.0005*), and significantly more non-episodic details when compared to negative non-genocide memories (t(195) = -2.822, β^ = -1.583, *SE* = 0.561, *p = 0.0268)*. There were no significant differences in any other post hoc contrast test for episodic details (negative non-genocide – genocide, t(206) = -2.229, β^ = -1.876, *SE* = 0.842, *p = 0.1188;* negative non-genocide – neutral, t(249) = 1.897, β^ = 2.221, *SE* =1.171, *p = 0.2319;* negative non-genocide – positive, t(245) = 0.249, β^ = 0.307, *SE* = 1.233, *p = 0.9946;* genocide – positive, t(222) = 2.013, β^ = 2.183, *SE* = 1.085, *p = 0.1864,* neutral – positive, t(248) = -1.405, β^ = -1.914, *SE* =

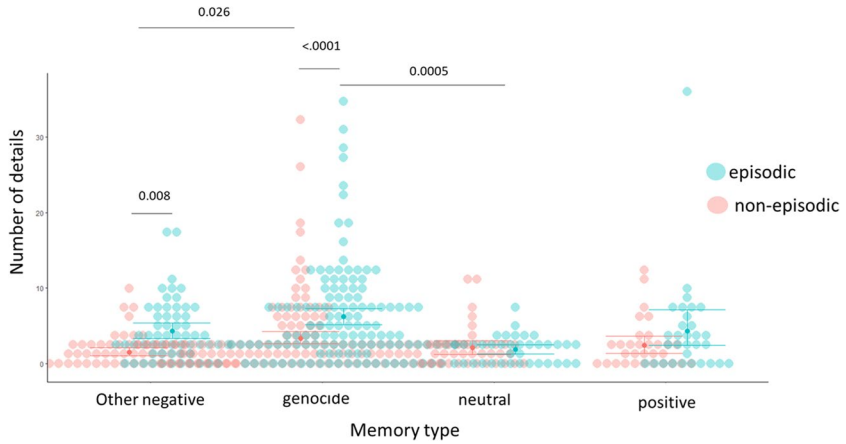

Fig. 1 Memory detail composition. Total number of details broken down into episodic and non-episodic categories, displayed for each participant across four conditions, bolded data points represent the mean for each condition, and error bars represent the bootstrapped 95% confidence intervals. There is a mnemonic enhancement (more episodic than non-episodic details) for memories of negatively valanced events, both from the genocide and that occurred outside of the genocide. Memories from the genocide are also more detailed overall (see Online Supplementary Material Fig. 1), with significantly more non-episodic details than other negative memories, and significantly more episodic details than neutral memories

1.363, $p = 0.4976$) or non-episodic details (negative non-genocide – neutral, t(242) = -0.317, β^ = -0.252, SE = 0.797, $p = 0.9890$; negative non-genocide – positive, t(233) = -0.675, β^ = -0.654, SE = 0.836, $p = 0.9064$; genocide – neutral, t(227) = 1.920, β^ = 1.331, SE = 0.693, $p = 0.2223$; genocide – positive, t(209) = 1.401, β^ = 1.019, SE =0.727, $p = 0.5000$; neutral – positive, t(239) = -0.337, β^ = -0.312, SE =0.927, $p = 0.9868$). Summary statistics for all memory types can be found in Table 1. We did a final analysis comparing the proportion (episodic details / total details) across conditions. Negative non-genocide memories had the highest density of episodic details (M = 0.77, SD = 0.29), followed by genocide memories (M = 0.61, SD = 0.37), positive memories (M = 0.57, SD = 0.41), and neutral memories (M = 0.52, SD = 0.37), pairwise comparisons revealed this difference was significant between negative non-genocide memories and neutral memories (t(190) = 2.720, β^ = 0.2408, SE = 0.0885, $p = 0.0357$).

```
null model episodic <- lmer(# episodic details ~ (1|Participant), dataframe)
episodic model <- lmer(# episodic details ~ memory type +(1|Participant), dataframe)
null model non-episodic <- lmer(# non-episodic details ~ (1|Participant), dataframe)
non-episodic model <- lmer(#non-details ~ memory type +(1|Participant), dataframe)
null episodic proportion model <- lmer(episodic/total +(1|Participant), dataframe)
episodic proportion model <- lmer(episodic/total ~ memory type +(1|Participant), dataframe)
```

Does cognitive flexibility shape memory recall?

Participants completed a verbal semantic fluency task as a measure of cognitive flexibility. They named as many exemplars as they could for three categories: animals, first names, and countries. On average, participants generated 15 correct animals (SD = 4.8, $range$ = 8–25), 17 first names (SD = 6, $range$ = 5–36), and 16 countries (SD = 4, $range$ = 5–41). We found that including a measure of cognitive flexibility, i.e., semantic fluency in the model to predict memory details outperformed a model without it ($\chi^2(2) = 12.336$, $p < 0.002095$) (model 2). Specifically, there was a main effect of fluency, with increased fluency predicting increased memory detail (t(254) = 3.394, β^ = 1.1995, SE = 0.3534, $p = 0.000798$). There was no interaction between detail type (episodic or non-episodic) and fluency, though visually the relationship appears to be driven by non-episodic rather than episodic details (Fig. 2). In a separate model with episodic details as the dependent variable (fluency episodic model), there was no significant impact of fluency (t(91) = 1.391, β^ = 0.7010, SE = 0.5039, $p = 0.168$), but using the number of non-episodic details (fluency non-episodic model) there was a significant positive relationship (t(94) = 2.634, β^ = 0.8518, SE = 0.3234, $p = 0.00985$).

```
null model episodic <- lmer(# episodic details ~ (1|Participant), dataframe)
fluency episodic model <- lmer(# episodic details ~ ZscoreFluency +(1|Participant), dataframe)
null model non-episodic <- lmer(# non-episodic details ~ (1|Participant), dataframe)
fluency non-episodic model <- lmer(#non-details ~ ZscoreFluency +(1|Participant), dataframe)
```

Table 1 Displays summary statistics for detail counts for each memory type

Memory type	Total details	Episodic details	Non-episodic details	Proportion of episodic details
Negative non-genocide	M = 6.02	M = 4.40	M = 1.62	M = 0.77
	CI [4.11– 8.49]	*CI [3.167 – 5.63]*	*CI [0.387 – 2.85]*	*SD = 0.29*
	Range = 1–19	*Range = 1–18*	*Range = 1–8*	
Genocide	M = 9.5	M = 6.16	M = 3.34	M = 0.61
	CI [7.71 – 10.52]	*CI [5.31 – 7.02]*	*CI [2.48 – 4.19]*	*SD = 0.37*
	Range = 1–45	*Range = 1–35*	*Range = 1–32*	
Neutral	M = 4.17	M = 1.98	M = 2.19	M = 0.57
	CI [1.24– 6.53]	*CI [0.414– 3.54]*	*CI [0.630 – 3.76]*	*SD = 0.41*
	Range = 1–12	*Range = 1–8*	*Range = 1–11*	
Positive	M = 6.2	M = 4.05	M = 2.15	M = 0.52
	CI [3.53 – 8.76]	*CI [2.4 – 5.75]*	*CI [0.453 –3.85]*	*SD = 0.37*
	Range = 1–47	*Range = 1–36*	*Range = 1–13*	

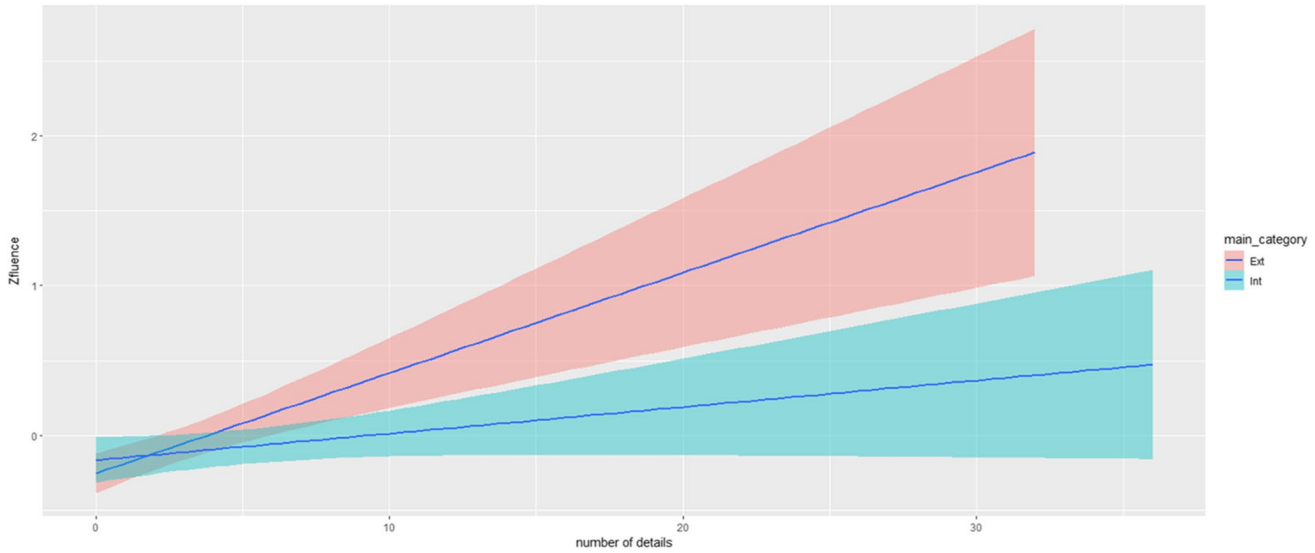

Fig. 2 Relationship between semantic fluency and autobiographical memory recall details. There is a significant positive relationship between fluency and the total number of details generated in memory narratives, with the effect being more prominent for non-episodic details

Do post-traumatic stress symptoms shape memory recall?

Participants completed the Post Traumatic Symptoms Checklist – Civilian (PCL-C) which measures current symptoms of post-traumatic stress on a scale of 17–85. Scores of 30–44 indicate moderate to high severity of symptoms, and 45–85 high severity. Participants in the current study ranged from 20-85 (*Mean = 41, Median = 41, SD = 15),* with 29% of participants scoring below 30, 37% of participants having moderate to high symptoms, and 34% having high severity symptoms. The model including an interaction between post-traumatic stress symptoms and type of memory detail (model 3) did not outperform the model without symptoms ($\chi^2(2) = 4.3273$, $p < 0.1149$).

Discussion

How are traumatic events remembered? Are they recalled differently from other events? Does this differ in those who suffer from post-traumatic stress? There is a long-standing debate between the idea that memories for traumatic events are fragmented, distorted, and missing central details, and evidence that these events are vivid, coherent, and detailed. The majority of this research has relied on subjective memory ratings. Here, we use the AI method to probe the structure of these memories and compare them to memories of other types of events. To our knowledge this has only been used in one other study (McKinnon et al., 2015) to examine trauma memories, and this study focused on memories within 5 years of the event. Here, we help fill this gap by examining memories of extremely traumatic events that occurred over 20 years ago, in Rwandan civilians who lived through the 1994 genocide in Rwanda. We found that memories of events from the genocide were mnemonically enhanced, specifically they were higher in episodic detail than non-episodic detail. This mnemonic enhancement was also present in negative events that occurred outside of the genocide, though memories from the genocide were more detailed overall. Somewhat surprisingly, we did not find any impact of PTS on memory details. We did find a general relationship with memory details and cognitive flexibility, with the number of details in memory narratives being positively linked to flexibility. Here we discuss these findings in further detail.

Are memories of the genocide recalled differently from other memories?

The finding that memories from the genocide are mnemonically enhanced replicates the McKinnon et al. (2015) report that memories for life-threatening events are enhanced episodically. Notably, participants in the Air Transat study recalled memories approximately 3.5 years after the event, whereas participants in our study were recalling events that happened more than 20 years ago. This, perhaps, makes the finding even more striking, given evidence that older memories are usually semanticized (for a review see Fan et al., 2022), and falls in line with evidence that fear memories last longer (see Dolan, 2002, and Hamann, 2001, for reviews), and are recalled more vividly (Brown & Kulik, 1977; Bahrick et al., 1998; Blumenthal et al., 2023; Budson et al., 2004; Peterson & Bell, 1996; Peterson & Whalen, 2001;

Paradis et al., 2004; Pezdek, 2003; Wolters & Goudsmit, 2005).

The fact that memories from the genocide were just as episodically detailed in individuals with and without PTSD converges with studies based on subjective ratings that find that traumatic events are accessible, and recalled vividly and in detail in individuals with and without PTSD (Bernsten & Rubin, 2014; Berntsen et al., 2003; Porter & Birt, 2001; Rubin et al., 2011, 2008a, 2008b). It also converges with Gray and Lombardo's (2001) finding that traumatic event narratives were longer than those for non-traumatic events in individuals with and without PTSD and were equally coherent (when controlling for general cognitive ability). While the present method was not designed to test the coherency of memories, it indirectly challenges theories that trauma memories are incoherent, as one study found that memories high in episodic detail are positively correlated with measures of spatiotemporal structure in recall (Diamond & Levine, 2020). In sum, the finding that traumatic memories from the genocide 22 years ago remain high in episodic detail, and do not differ in individuals with higher PTSD symptoms, as well as the finding in our study and others that memories of negative emotional valence also have increased episodic details (Sheldon & Donahue, 2017; Wardell et al., 2021b) challenges theories such as the "dual representation model." Specifically, the dual representation model purports that unlike non-trauma memories, trauma memories are encoded in the brain through emotional and sensory systems, making involuntary recall vivid and sensory, but voluntary recall difficult, and at best fragmented or incoherent (Brewin, 2014; Brewin et al., 2010). Instead, the present results support the idea that traumatic events are encoded, consolidated, and retrieved within the same system as other events, and are enhanced through the same mechanisms (for a review, see Sheldon et al., 2018).

Interestingly, memories from the genocide did differ from other types of memories, including other negative-valanced memories, in that they had more non-episodic details. Given that the interview is not designed to test non-episodic knowledge, non-episodic details are considered incidental, which makes interpretation of them more challenging (see Melega & Sheldon, 2023, for a discussion). Nevertheless, we explored the composition of subcategories and relevant literature to try to gain more insight into this pattern. Note that since this was post hoc and exploratory, and the overall detail counts were relatively low for analyzing subcategories, we did not run any inferential statistical analyses. We found that the non-episodic category was composed primarily of the subcategory semantic details, including both personal and general semantic details, followed by the subcategory "external events" consisting of referral to events outside of the specific event described. The semantic subcategory is the most common subcategory of non-episodic details reported in other studies with healthy adults (Fan et al., 2022; Levine et al., 2002; Simpson et al., 2023). We categorized semantic details into general semantics (e.g., Kigali is the capital of Rwanda) and personal semantics ("I was 17 when the genocide began"), following Renoult et al. (2020) and found that memories included both categories, with a higher proportion of personal semantic details. An examination of semantic details and external events referenced showed that these details were usually highly relevant, for example when describing a specific event from the genocide, participants would reference other events from this time period, providing more elaborate context.

One possibility is that a collective event of huge historical importance, such as the genocide, may enrich memories in specific ways that are captured by the non-episodic category. Events that drastically alter an individual's daily life, creating a stark "before" and "after" are known to be especially important for defining oneself and identity (Brown et al., 2009), which could potentially explain the increased personal semantic details present in these memories. Further, surprising events with sharp before and after boundaries lead to a bump in the number of autobiographical events recalled in that time period (Brown, 2021). For example, a recent study of autobiographical memories during the COVID-19 pandemic found that participants in the USA recalled more autobiographical memories from March 2020 (the first pandemic lockdown) than from any other month that year, and events were perceived as compressed in time during this period (Rouhani et al., 2023). This could explain the frequent references to genocide-related external events present in these memories. A non-exclusive possibility is that general semantic details and context are embedded through post-genocide collective remembering practices, such as Gacacas (a form of community trials), yearly weeks of remembrance, and widely visited memorials and museums. This contextual embedding could be particularly present in our study, because participants were sharing memories of this event with foreign research assistants. On the latter point, during debriefing after the session, a number of participants shared that they were grateful to have shared their memories, as it is important that the world not forget what happened.

Do post-traumatic stress symptoms shape memory recall?

In addition to examining the structure of genocide memories, we wanted to understand whether these memories differed in participants with higher PTS symptoms. We found that the composition of details in memories of the genocide did not differ as a result of PTS. In fact, we found no differences in memory details across memory types. This was surprising, as we hypothesized that individuals with more PTS symptoms would have either

increased non-episodic details (as reported in McKinnon et al., 2015) or both an increase in non-episodic details and a decrease in episodic details (as reported in Brown et al., 2013). One major difference between our study and these is the length of time passed between traumatic events and study recall, while it was 22 years since the event in our study, in the other studies it was a maximum of 3.5 years.

Does cognitive flexibility shape memory recall?

Our initial hypothesis was that individuals with higher PTS would have more non-episodic details across all memories, and that this would be related to cognitive flexibility. However, we did not find evidence of a relationship between PTS and memory details. We did find a positive relationship between semantic fluency and memory details. Specifically, participants with higher verbal fluency had more memory details. In general, this is not surprising, given our measure of cognitive flexibility is verbal fluency, and we examine verbal recall of memories. However, links between neuropsychological tasks and more naturalistic measures, like memory narratives are not a given (see McKinnon et al., 2008). Further, it is not to be taken for granted when these types of tasks, imported from the minority world, work in majority world settings (much less with sensical links between them). Further, one might expect this to equally impact episodic and non-episodic details, but in our sample it is driven primarily by an increase in non-episodic details (Fig. 2). This is somewhat surprising from the perspective that semantic fluency is a measure of cognitive flexibility, specifically in monitoring memory content during narrative recall. If that is the case one might expect fluency to be related to a decrease in non-episodic details (since they are technically off task), or an increase in episodic details retrieved. However, in the context of our study, where the non-episodic category contains very few repetitions or "other" details, and in the case of genocide memories is rich with relevant non-episodic information, individuals with high semantic fluency could be using their semantic system to provide contextualization and meaning to memories. If this is the case, it provides a new outlook on the relationship between fluency and memory recall, as well as on semantic embellishments in event memory recall. In other words, instead of being considered off-task, memories rich in both episodic and relevant non-episodic details, could be considered particularly rich or meaningful. Future work will need to more precisely pick apart contributions of semantic richness versus flexibility to both tasks, potentially by using non-verbal measures of cognitive flexibility.

Limitations and future directions

This study has a number of limitations. One limitation is that it was designed based on the AMT (Williams et al., 2007), which uses differently valanced cue words to aid participants in generating a memory of a specific event but does not necessarily emphasize verbal elaboration of event details, unlike the AI method. It is therefore likely that the additional guided prompting from the AI may have increased the number of details provided by participants. This is an important follow-up for future research, especially for comparing memory specificity more generally between different cultures. In other words, it will be important to compare the level of details in Rwandan participants' memories with other groups using the AI method to ensure level of detail is not impacted by methodological variations. However, crucially in this study, even if memories of all valence types are less detailed overall, this doesn't impact our main finding – that genocide memories have increased details and increased episodic details. Another major limitation of this study is that events outside of the genocide were not dated, confounding remoteness of memory and valence. We think it is likely that the majority of memories recalled occurred more recently than the genocide, since it is easier to access more recent memories. If this is the case, the fact that genocide memories are still more detailed overall, and enhanced in episodic detail, is even more striking. However, this is an assumption, and future work that matches valence across time period in the design up front or asks participants to rate the remoteness of memory will be an important follow-up. A final limitation is that we do not have a metric of how often participants rehearsed different types of memories, in particular genocide memories. Rehearsal could occur verbally in different contexts (i.e., with a close family member or friend, or during a memorial, at a Gacaca), or through internal replay in different contexts. The number of times a memory is recalled and verbalized, and in which contexts is an important area of future investigation.

Conclusion

Of the global population, 69–89% will experience at least one traumatic event in their lifetime (Breslau, 2009; Resnick et al., 1993; Van Ameringen et al., 2008), and many individuals, particularly those living in war zones or regions of political violence and instability, are likely to experience multiple. Understanding how individuals remember these events is thus not only a fascinating question for basic science, but important for understanding

the resilience or the development of psychopathology and recovery. Here, we approached this question by quantifying the types of details in memory narratives in a unique population, individuals who lived through the 1994 genocide in Rwanda. We found that even 22 years later, memories from this time period are vivid and episodically rich, and are also rich in semantic detail related to the genocide. These results support the idea that traumatic events lead to enhanced long-lasting memories, and that collective events of great importance may also enrich memories with relevant contextual and semantic detail.

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Data Availability Raw data is not available, given we did not have informed consent for data sharing at the time of data collection.

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