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The frequency and cueing mechanisms of involuntary autobiographical memories while driving

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ABSTRACT
Involuntary autobiographical memories (IAMs) have been typically studied with paper diaries, kept for a week or longer. However, such studies are unable to capture the true frequency of IAMs, nor the level of detail that would give new insights into the mechanisms of IAMs. To address this gap, a new audio-recording method was developed and tested on the first author who recorded 674 IAMs while driving a car on a 30–40-minute-long habitual route on 20 occasions. Results revealed very high frequency of IAMs (almost 34 per journey) that were reported more often in response to dynamic (one-off) than static cues. Moreover, a substantial number of memory chains and long-term priming of IAMs by previously encountered incidental stimuli were also recorded. Based on these results, a new theoretical model is proposed in which the occurrence of IAMs is determined by an interplay of factors at the time of the IAM, such as the type of ongoing activity and internal or external triggers, as well as different types of long-term priming. The results also have practical implications for studying mind-wandering and safety issues in driving and aircraft-flying, where periods of concentration are followed by monotony and less demanding tasks.

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Involuntary autobiographical memory; dynamic and static memory cues; memory chaining; mind-wandering; driving; self-study

Research on spontaneous cognitions has grown substantially over the past decades and involves studying a variety of phenomena such as spontaneous task-unrelated thoughts or mind-wandering (Smallwood & Schooler, 2015), involuntary autobiographical memories (Berntsen, 2009; Mace, 2007) and more recently involuntary thoughts about the future (Cole & Kvavilashvili, 2019). All these phenomena involve thoughts and memories coming to mind unintentionally while being engaged in mundane everyday activities (e.g., driving, washing up, etc.), but traditionally, they have been studied within separate fields of enquiry. Only recently have researchers started to examine potential similarities between them using diary, experience sampling and experimental methods, and there is a growing consensus that research on the temporal focus of mind-wandering such as thoughts about the past and the future may overlap with the phenomena studied within the fields of involuntary autobiographical memories (IAMs) and involuntary future thinking (Berntsen, 2019; Kvavilashvili & Rummel, 2020; Plimpton et al., 2015).

The focus of the present paper is on studying IAMs and their potential retrieval mechanisms in everyday life using a novel audio recording method in which the first author recorded his IAMs while driving to work via a predetermined route on multiple occasions ($n = 20$). The single-case approach, adopted in the present study, follows a long tradition of memory researchers collecting extensive data on themselves and has been particularly popular among researchers of autobiographical memory (Conway et al., 1996; Galton, 1879; Linton, 1975; Wagenaar, 1986). The new method resulted in recording a high frequency of IAMs not reported previously in the literature, and enabled the examination of hitherto little studied effects of static and dynamic cues, internal memory chaining and long-term priming that are also relevant to current research on mind-wandering and on the safety of driving (Chapman et al., 1999; Galera et al., 2012; Parker et al., 1995).

Autobiographical memories are memories of events from one's personal past and can vary greatly in terms of their content and phenomenology (Conway, 1990). They can be of recent or distant events, and vary in emotional valence, specificity, visual perspective, and other characteristics. Although autobiographical memories can be retrieved voluntarily when responding to a request for information or completing a particular action (Berntsen, 2010), in everyday life, they often come to mind "unbidden" or involuntarily, without a deliberate attempt to retrieve them (Salaman, 1970). Despite the ubiquity of

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IAMs in everyday life, for several decades researchers focussed on voluntarily recalled autobiographical memories before research on IAMs started in the late 1990s (Berntsen, 1996, 1998).

Initial research on IAMs was almost entirely based on diary methods (Berntsen, 1996; Kvavilashvili & Mandler, 2004; Mace, 2005) in which participants recorded IAMs and rated their characteristics in structured paper diaries. Laboratory methods have been also developed to study involuntary memories under more controlled conditions, allowing the manipulation of several key variables (e.g., types of cues, levels of concentration, etc.) associated with the occurrence of IAMs and testing theories about underlying mechanisms of IAMs (Ball, 2007; Berntsen et al., 2013; Mace, 2006; Mazzoni et al., 2014; Plimpton et al., 2015; Schlagman & Kvavilashvili, 2008; Vannucci et al., 2014).

Despite substantial progress made in research on IAMs, there are several unanswered questions. One question refers to the frequency of IAMs in everyday life. In a study where the burden of recording detailed reports in a diary was removed and participants merely had to press a button on a mechanical counter, a mean of 22 IAMs in a day was reported (Rasmussen & Berntsen, 2011). Moreover, using an experience sampling method, Gardner and Ascoli (2015) estimated that autobiographical memories were occurring every 2–4 min, although they did not distinguish between IAMs and voluntary autobiographical memories. Similar high frequencies could be inferred from laboratory studies where participants, despite large individual differences, recorded about six to seven memories in a 15-minute-long vigilance task (Kvavilashvili & Schlagman, 2011; Schlagman & Kvavilashvili, 2008). Thus, the frequency of IAMs appears greater than originally appreciated and is an important empirical question that needs further examination.

The frequency of IAMs is also related to a question about underlying mechanisms of IAMs because their occurrence may be influenced by variables such as the nature of ongoing activities, types of triggers, and prior exposure to memory-related material. For example, there is strong evidence from IAM research, and related fields such as mind-wandering, that spontaneous thoughts and memories occur more often when people are engaged in undemanding, habitual activities, for example, making coffee, brushing teeth, or driving (Berntsen, 1996; Giambra, 1995; Kvavilashvili & Mandler, 2004; Schlagman & Kvavilashvili, 2008). Conversely, IAMs are less frequent when undertaking cognitively demanding tasks (Vannucci et al., 2015). It is therefore possible that the frequency of IAMs fluctuates considerably throughout the day and across different time periods, depending on activities that a person is predominantly being engaged in (e.g., revising for exams for several hours versus driving a familiar route for the same amount of time).

Another important feature of IAMs is that they often occur in response to easily identifiable triggers in one's environment or thoughts (Mace, 2004; Mazzoni et al., 2014). In most diary studies, cues have been reported in a large percentage of cases, for example, in 93% of 700 memories in a study by Berntsen (1996) and in 91% of 238 involuntary memories in a study by Schlagman and Kvavilashvili (2008). Moreover, the majority of cues were external (environmental) rather than internal (e.g., from thoughts while planning, or retrieval of other information), with a much smaller percentage of cases with no identifiable trigger (Berntsen, 1998; Berntsen & Hall, 2004; Berntsen & Jacobsen, 2008; Schlagman et al., 2007; Schlagman & Kvavilashvili, 2008).

One interesting but under-explored aspect of internal cues is where a sequence of IAMs occurs. The term *chaining* was coined by Mace (2006), referring to a phenomenon where an initial memory, which could be deliberately retrieved or spontaneous, triggers a subsequent IAM, which may in turn trigger the next IAM, and further. A chained memory, cued by an immediately prior memory, is, by definition, internally cued because a triggering memory is an internal mental event. In self-reporting methods, such as diaries or surveys, participants may not report the chained memories as they are not usually briefed to monitor for them. If participants do observe them, they may choose to report only the first memory, or aggregate the multiple memories into a composite memory description, making them harder to identify and quantify.

Beyond the immediate effect of chaining, with minimal delay between subsequent memories, there is evidence that IAMs can be primed from some time earlier, i.e., by earlier recollections of autobiographical memories or previously encountered incidental cues influencing later spontaneous recollections (Mace, 2010). For example, in a two-week diary study of IAMs (Mace, 2005), at the end of week 1, participants spent 30 min in the laboratory deliberately recalling high school memories. In week 2, IAMs pertaining to high school (but not the ones that were recalled in the laboratory) appeared in the diaries. Similarly, participants who reminisced about high school between two laboratory tasks for 15 min showed a (small) increase of high school IAMs in response to incidental cue-words encountered during the subsequent vigilance task (Barzykowski & Niedźwieńska, 2018). While in these studies this reminiscence priming manipulation was very strong (lasting 30 and 15 min, respectively), it is highly probable that accidental encounters with certain events or ideas, outside of researchers' control, will also prime memories, so that later when certain cues are encountered these memories pop into mind.

In line with this idea, recent studies by Mace and colleagues have used priming manipulations with a variety of stimuli (words, sentences, images), and have shown that participants who were exposed to a word "cat" were more likely to recall a voluntary autobiographical memory or an IAM involving a cat (e.g., a cat jumping out of the window) in response to an unrelated cue word such as "window" than control participants who were not previously exposed to the word "cat" (Mace et al., 2015; Mace et al., 2019; Mace & Petersen, 2020). Findings from these studies suggest that such semantic to autobiographical memory priming is a common occurrence, with presented concepts activating autobiographical memories that incorporate those concepts (Mace et al., 2023; Mace & Hidalgo, 2022; Mace & Kruchten, 2023; Mace & Petersen, 2020; Mace & Unlu, 2020).

Kvavilashvili and Mandler (2004) proposed that the activations by chance exposure to incidental stimuli could be long-lasting, resulting in memories coming to mind a while after the priming stimulus or event occurred. Evidence for such long-term priming comes from a recent laboratory study of Mace and Hidalgo (2022) who demonstrated the semantic to autobiographical memory priming after a delay of seven days (see also Mace & Petersen, 2020, who demonstrated priming effects after a 24-hour delay). However, in everyday life, the priming event may be easily forgotten or difficult to trace (for examples, see Kvavilashvili & Mandler, 2004). This then raises interesting methodological questions about whether there is a way of detecting earlier cues, or primes, and measuring their effects in diary studies of IAMs.

In summary, there are several gaps in research on IAMs that need to be addressed. These refer to questions about the frequency of IAMs in everyday life, especially during cognitively undemanding habitual activities that have been shown to increase the number of IAMs in laboratory studies. More research is also needed to study the role of internal triggers in eliciting IAMs, especially in terms of memory chaining that has been mostly overlooked by previous research on IAMs. Equally, in relation to external triggers more research is needed to examine why a particular cue triggers an IAM on one occasion but not on another, or what is the time delay between a cue and elicited memory that determines whether the cue can be counted as an immediate trigger or a priming event.

The present study

Although the frequency of IAMs recorded in diary studies is largely consistent (Berntsen, 1998; Kvavilashvili & Mandler, 2004; Mace et al., 2011; Schlagman et al., 2007), they did not seem to concur with the first author's self-observations. In particular, when driving on a familiar route where he noticed many IAMs, cued by what he was seeing outside the car, hearing inside the car (radio or music), physical sensations (e.g., temperature, discomfort), and thoughts about events prior to departure, or anticipated after the journey. Based on these self-observations, in the present study, we used car driving as a naturalistic activity where IAMs could be audio-recorded with little disruption to the task. The method arose from using a recorder to capture free-flowing thoughts while driving, which could not be recalled at the end of the journey. Using the audio recording, IAMs could be described in greater detail, transcribed later, and analysed. An initial pilot of a couple of journeys showed a surprising range of memories (numerically and their types) and that the method was feasible without negatively affecting driving.

There is an extensive literature on the psychological aspects of driving, for example, automaticity and inattention blindness while driving on familiar roads (Charlton & Starkey, 2013). Most drivers will have experienced arriving at a point without any recollection of the previous few minutes, driving without attention or without awareness (Brown, 1994), realising the gap at the end of the attention lapse (Chapman et al., 1999). Distracted driving ("How did I get here?") suggests that the mind is somewhere else (Charlton & Starkey, 2011; Groeger, 2002; May & Gale, 1998). Indeed, a survey study of drivers (Berthié et al., 2015) found that 85% of drivers reported mind-wandering for a substantial amount of time during their most recent car trip, and research in hospital emergency departments after accidents found that more accidents were associated with mind-wandering when the driver was at fault, than when the driver was not at fault (Galera et al., 2012).

While driving requires vigilance and attention, there is automaticity about the activity. An experienced driver on a familiar route may not be under great cognitive load. Driving might therefore be an ideal activity for cognitive research because of its semi-automatic nature, which is conducive to mind-wandering and other involuntary phenomena. People move in and out of mind-wandering as they approach hazards and need to concentrate. Therefore, a standard journey, such as a commute, is potentially a good way to study IAMs in a controlled, regular environment where the same things happen. Importantly, driving a consistent route multiple times provides a unique opportunity to compare the effects of static versus transient cues in eliciting IAMs, a theoretically interesting question that has never been examined before in diary and laboratory studies of IAMs. For example, there are potential cues that will always be present (e.g., buildings, landmarks, road signs etc.), while other cues will be dynamic, and perhaps unique to a journey, for example, a commercial vehicle with a company logo, a certain model or colour of car, or piece of music playing in the car.

Although the study was largely exploratory, it was anticipated that a larger number of IAMs would be noted in the relatively short journey time, due to the automatic nature of driving, compared with the rates seen in the longer studies and more formal diary recording (Laughland & Kvavilashvili, 2018). It was also expected that the majority of memories would have identifiable cues which were external more often than internal, in line with previous findings (Berntsen, 1996; Berntsen & Hall, 2004; Kvavilashvili & Mandler, 2004; Schlagman et al., 2007). Finally, it was predicted that IAMs recorded while driving would be predominantly specific rather than general, as is found in diary studies (Ball & Little, 2006; Berntsen, 1998). However, no specific predictions were made about IAMs recalled in response to static versus dynamic cues or memory chaining and long-term priming by IAMs and incidental cues.

Method

Participant

The first author was the participant. He was aged 54 years 3 months at first journey to 55 years 11 months at the final journey. He passed his driving test aged 17 years and had driven regularly since age 22.

Journeys

Despite the exploratory nature of the study, we planned to record between 20 and 24 journeys with the possibility of increasing the number to 30 if the number of collected IAMs was less than 10 IAMs per journey. A total of 22 journeys were collected. However, one was abandoned because of an incoming phone call, and another because a highly absorbing radio programme started and prevented the participant from noticing and recording any IAMs. The data presented in this paper is therefore based on 20 journeys.

The participant often worked from home and did not drive to campus every day. In addition, when he drove to university it often happened in the morning rush hour, which could result in prolonged driving time and stress because of heavy traffic and being late. Therefore, recordings were made only on those days when the participant left the house after 9:30 am which would avoid any delays in driving time and ensure that the participant was in a relaxed state of mind. Given these constraints, it was expected that the data collection would span across a 12–14-month period which would also ensure the consistency of data across time.

The first two journeys were pilot recordings to test the feasibility of the method but as they went well, they were included. The majority of journeys were recorded in year 1 (10 in February and March and three in September and October), and the remaining five journeys in January and February of year 2. Data from the 10 journeys in the intensive period in year 1 were comparable with the other, earlier and later 10 journeys. All journeys followed the same route in the same direction (see Procedure).

Materials

The audio recordings were made using an Olympus WS-811 digital recorder, with "tie-clip" microphone. Audacity audio software was used to play back the MP3 audio files for transcription of memory events and noting time into journey (Audacity, 2016).

Procedure

A standard journey was used, between the participant's home and the University car park. This was a very familiar journey driven by the participant many times before starting the experiment, and on other days when not recording the journeys, using a consistent route. The distance was 38.7 km, and typically took about 37 min to complete. The journeys were selected for recording where it was expected that they would follow a standard pattern of journey time outside the morning rush hour or peak period (i.e., after 9:30 am). This would ensure that the car was moving normally all the time apart from mandatory stops at traffic lights and junctions, avoiding prolonged periods in stationary traffic. The recording was started immediately before pulling away, with the participant recording a sentence or two about what had happened before leaving, and expectations in the day ahead, for context, and continued until pulling into a parking space at the university.

While driving, the participant commented from time to time on what he was observing, in addition to recording memories when they occurred. This was not a continuous narrative, and hence there were periods of silence, even though the recording was continuous. Expressing some of his inner thoughts out loud helped the participant to keep the mind active in terms of metacognition by reminding that he was doing the experiment as well as helping him to keep track of what was going around him (especially when something unexpected happened). Later, these occasional comments turned out to be very useful in discovering otherwise unidentifiable links between the environment and subsequently recorded involuntary memories (see Results). Each time the participant was aware of an IAM, he described it and, where possible, identified the trigger. No other information was gathered at this point to ensure safe driving, but memory descriptions and other comments were later used to code memory characteristics such as specificity and emotional valence (Berntsen, 2009). Given the frequency of IAMs and the overall need to drive safely, descriptions were occasionally curtailed.

Scoring

After all the journeys were gathered, the audio files were played back by the first author and transcribed in a notebook in sufficient detail to identify characteristics of the memories, and to record other salient comments about the journey. The journeys were reviewed in reverse chronological order, i.e., the most recent journey was transcribed first. This approach was serendipitous, but revealed some interesting insights, for example, it was easier to notice memories that repeated, or were similar, across journeys. On transcription, each IAM was classified by the first author as specific or general, and rated as a positive (+1), negative (−1) or neutral memory (0). A full 5-point Likert scale spoken at the time would have been disruptive and was not realistic given the need to drive safely. In line with paper diary studies, the trigger was evaluated as external, internal or that there was no apparent trigger. For those identified as having an external trigger, the cue was further classified as a static or dynamic cue.

Static cues were cues that were always present in the journey (such as a landmark or road sign), while dynamic cues were random, transient items encountered on one occasion only (e.g., another vehicle, or a particular piece of music playing, or some change to the usual, such as a petrol station sign not working).

Data analysis

For majority of the analyses, presented in the results section, the unit of analysis was the journey made by the participant. Hence, the data presented in tables refer to dependent variables per each of the 20 journeys made (e.g., number and percentages of external vs. internal cues, static vs. dynamic cues, specific vs. general memories, etc.), and paired samples t-tests were conducted to compare the numbers or percentages across 20 journeys. Effect sizes were measured by Cohen's d with .20, .50 and .80 referring to small, medium, and large effect sizes, respectively (Cohen, 1988).

Results

Number of recorded IAMs

A total of 674 IAMs were recorded over 20 journeys, with a mean of 33.70 ($SD = 7.57$) per journey (minimum 19, maximum 44). There was no significant difference between the mean number of IAMs in the first 10 journeys ($M = 31.00$, $SD = 8.11$) versus the second 10 ($M = 36.30$, $SD = 6.29$), $t(18) = 1.63$, $p = 0.120$, suggesting that there was a consistency over the many months of recording. The mean journey time across 20 journeys was 37 min 42 s ($SD =$ 3 min and 1 s). The mean rate of memories was 0.90 memories per minute, which equates to a mean time between consecutive IAMs of 71 s, with a minimum of 52 s, and a maximum of 117 s across all journeys. A full breakdown of journey durations, number of memories in each journey and rates of occurrence is given in Table 1.

Table 1. Total number of memories, journey durations, number of memories per minute and time between memories in each journey.

Journey number	Number of memories	Journey duration (mm:ss)	Memory rate (memories per minute)	Mean time between memories (Seconds)
1	25	34:30	0.72	82.80
2	43	39:58	1.08	55.77
3	34	37:58	0.90	67.00
4	29	39:05	0.74	80.86
5	20	39:06	0.51	117.30
6	33	33:31	0.98	60.94
7	31	34:35	0.90	66.94
8	34	36:41	0.93	64.74
9	42	36:31	1.15	52.17
10	19	33:59	0.56	107.32
11	26	46:48	0.56	108.00
12	28	35:06	0.80	75.21
13	39	35:54	1.09	55.23
14	32	38:02	0.84	71.31
15	42	39:27	1.06	56.36
16	44	40:53	1.08	55.75
17	39	37:00	1.05	56.92
18	37	39:33	0.94	64.14
19	44	37:47	1.16	51.52
20	33	37:33	0.88	68.27

Triggers

A summary of the cue types and proportions for each journey is given in Table 2. Externally cued memories formed the largest proportion ($N = 332$, 49%), with percentages varying from 20% to 76% per journey, while 39% per cent were internally cued ($N = 266$) with percentages varying from 19% to 67% per journey. No cues were identified on only 11% of recorded memories ($N = 76$). Overall, across all journeys there was a clear picture of memories having an identifiable cue, whether internal or external (89%). Although the mean number of externally cued memories ($M = 16.60$, $SD = 5.85$) was greater than internally cued memories ($M = 13.30$, $SD = 5.93$) across 20 journeys, this difference was not statistically significant, $t(19) = 1.74$, $p = .099$.

Internal triggers and chaining

However, many of the internally cued memories were in fact cued by the immediately preceding recorded memory, rather than internal thoughts. For example, in journey 19, the participant was aware of tyre/road noise (external cue), which led to thoughts of him driving in the USA where, in his experience, the road surfaces are noisy (a general IAM), which led to him remembering driving in Seattle the previous year trying to find the Air and Space Museum and getting lost and a bit anxious (specific IAM). While in journey 10, the participant was thinking about a computer he had ordered, which would have Microsoft Windows 8 installed (specific IAM), which led to recollection of a Microsoft seminar he attended where they were giving out copies of Windows 8 (specific IAM).

A chained memory cued by an immediately prior memory is internally cued, and this is how they are represented in Table 2. However, as a high number of chained memories were detected they were re-coded as memory (IAM) cued, rather than cued by internal thoughts. Table 3 shows the chained memories separated out from the internally cued memories (memory cue versus thought cue). With the number of IAMs cued by internal thoughts reduced ($M = 6.55$, $SD = 4.15$), the difference between these internally cued, and externally cued IAMs ($M = 16.60$, $SD = 5.85$) became highly significant, $t(19) = 5.76$, $p < .0001$, *Cohen's d* $= 1.29$ (for similar findings concerning higher percentages of external than internal (thought based) cues of IAMs, see Berntsen, 1998, and Schlagman & Kvavilashvili, 2008, Study 2).

It was therefore possible to count chain events in each journey and determine chain lengths. Out of 674 recorded IAMs, 135 observations were classified as being part of 91 memory chains. Chains were observed in all 20 journeys,

Table 2. The number (percentages) of involuntary memories as a function of type of reported cue (external, internal or no cue) in each journey.

Journey number	External cue *N* (%)	Internal cue *N* (%)	No cue *N* (%)	Total (100%)
1	19 (76%)	5 (20%)	1 (4%)	25
2	30 (70%)	8 (19%)	5 (11%)	43
3	17 (50%)	14 (41%)	3 (9%)	34
4	15 (52%)	10 (34%)	4 (14%)	29
5	4 (20%)	11 (55%)	5 (25%)	20
6	17 (52%)	7 (21%)	9 (27%)	33
7	15 (48%)	13 (42%)	3 (10%)	31
8	15 (44%)	15 (44%)	4 (12%)	34
9	18 (43%)	19 (45%)	5 (12%)	42
10	7 (36%)	6 (32%)	6 (32%)	19
11	17 (65%)	7 (27%)	2 (8%)	26
12	14 (50%)	6 (21%)	8 (29%)	28
13	22 (56%)	15 (39%)	2 (5%)	39
14	21 (66%)	10 (31%)	1 (3%)	32
15	20 (48%)	18 (43%)	4 (9%)	42
16	22 (50%)	17 (39%)	5 (11%)	44
17	9 (23%)	26 (67%)	4 (10%)	39
18	16 (43%)	20 (54%)	1 (3%)	37
19	22 (50%)	20 (45%)	2 (5%)	44
20	12 (36%)	19 (58%)	2 (6%)	33
Total	**332 (49%)**	**266 (39%)**	**76 (11%)**	**674**

with a minimum of one chain per journey and a maximum of 11 chains. The number of chains observed in each journey, and the maximum chain length for each journey are shown in Table 4.

The minimum chain length is, by definition, one link, which was recorded in five journeys. The longest chain length observed was six, i.e., an initial memory followed by a cascade of six chained memories. The frequency distribution of chain lengths for 91 chains is shown in Table 5. Quite clearly, most chains were only one link long, so only one memory was prompted from the initial memory, but longer chains were observed, even to the extent of five or six memories following from the initial memory cue.

Table 3. The number (percentages) of involuntary memories as a function of type of reported cue (external, internal memory or internal thought) in each journey.

Journey	External	Internal memory cue	Internal thought cue	Total
1	19 (79%)	4 (17%)	1 (4%)	24
2	30 (79%)	6 (16%)	2 (5%)	38
3	17 (55%)	6 (19%)	8 (26%)	31
4	15 (60%)	8 (32%)	2 (8%)	25
5	4 (27%)	4 (27%)	7 (47%)	15
6	17 (71%)	4 (17%)	3 (13%)	24
7	15 (54%)	4 (14%)	9 (32%)	28
8	15 (50%)	10 (33%)	5 (17%)	30
9	18 (49%)	16 (43%)	3 (8%)	37
10	7 (54%)	4 (31%)	2 (15%)	13
11	17 (71%)	2 (8%)	5 (21%)	24
12	14 (70%)	4 (20%)	2 (10%)	20
13	22 (59%)	11 (30%)	4 (11%)	37
14	21 (68%)	5 (16%)	5 (16%)	31
15	20 (53%)	7 (18%)	11 (29%)	38
16	22 (56%)	7 (18%)	10 (26%)	39
17	9 (26%)	16 (46%)	10 (29%)	35
18	16 (44%)	11 (31%)	9 (25%)	36
19	22 (52%)	5 (12%)	15 (36%)	42
20	12 (39%)	1 (3%)	18 (58%)	31
Totals	**332 (55%)**	**135 (23%)**	**131 (22%)**	**598**

For example, in journey 6, a five-long chain related to a conversation the participant had had with a schoolteacher about the school's website and a tweet he had shown her, which led to recollections of several other tweets that he had made, or tweets that had amused him.

External triggers

Externally cued memories (332 out of 674) were further analysed to determine if they were triggered by static cues (e.g., buildings, landmarks, road signs always present in the journey) or dynamic cues (i.e., triggers that were not consistently there, such as other vehicles, music playing in the car, weather conditions, etc.). The breakdown of external cues into static and dynamic, by journey is shown in Table 6.

Across all 20 journeys, as many as 66% (218) of memories were triggered by dynamic cues, while 34% (114) were triggered by static cues. The percentage of memories with dynamic cues ranged from 14% to 84% per journey, while the percentage of memories with static cues ranged from 16% to 86% per journey. With a few exceptions (5 out of 20 journeys), the dynamic cues outweighed the static cues, and the number of dynamic cues ($M = 10.90$, $SD = 4.98$) was significantly higher than the number of static cues ($M = 5.70$, $SD = 3.10$), $t(19) = -3.95$, $p < .001$, *Cohen's* $d = .88$.

Analysis of external static cues

The 114 static triggers were therefore further analysed and 56 unique, or different, triggers in the journey were identified (e.g., road signs, petrol stations etc.). Of these, 30 triggered only one memory each across all 20 journeys, i.e., these cues were always present but cued a memory only once in the 20 journeys that were monitored. The other 26 triggers cued a memory in more than one of the journeys. The breakdown of static triggers, and the number of memories they cued is shown in Table 7.

Of interest were the 30 different cues that triggered only one memory, which means that the participant passed these 19 times out of 20 journeys without having any memory triggered. This raises questions about attention, and whether these cues were noticed, but did not activate a memory. On other occasions, the same or a different memory came up (from 2 to 8 times), but clearly not on all 20 occasions, and not every time in the many unrecorded journeys made over the past few years. Importantly, of the 26 static cues responsible for eliciting more than one memory (i.e., after subtracting the 30 that only cued one), they were not always of the same event. For example, there was a lay-by on the route where a mobile police speed camera was sometimes parked. On some occasions, it cued a memory of the time when the participant had not realised there was a camera there and was concerned that he might have been going too fast and receive a ticket for speeding, while on other occasions he recalled having an impatient

Table 4. Number of chains in each journey and the maximum chain length in that journey.

Journey	N of chains	Maximum chain length
1	1	1
2	5	1
3	6	3
4	10	3
5	6	2
6	3	5
7	4	2
8	7	3
9	3	2
10	2	1
11	3	2
12	11	3
13	4	6
14	2	3
15	3	2
16	4	1
17	5	3
18	3	3
19	5	2
20	4	1

driver behind when he was driving cautiously in anticipation of a speed camera being there.

Two of the static cues were locations where the participant had, in the past, turned off the route for a different destination. In each case three different memories were evoked. These were potentially decision points in the journey, which may have changed the state of attention. Some static cues, on the other hand, related to points where the participant had to become more alert, such as whether there might be a mobile speed camera (7 IAMs), or where more care was needed changing lanes (5 IAMs), or at the end of journey (6 IAMs) where he had to make decisions (e.g., assess parking options, or starting to focus on next actions). While others related to strong emotional links, for example, where he witnessed an accident (3 IAMs), or relevant to significant personal matters, such as a care home that brought to mind eight memories of caring for, visiting, or discussing care of elderly relatives.

Priming of involuntary autobiographical memories

In diary studies, participants can identify an external or internal trigger for most IAMs, but occasionally report that there was no trigger. Where there is no apparent trigger, this could be that there was a trigger, but the participant did not notice it, or there was genuinely no trigger and the IAM arose spontaneously. A third possibility is that there was some kind of priming event a while before, which the participant cannot recall, or cannot relate to the IAM (Kvavilashvili & Mandler, 2004). If this is the case, any such link is typically lost in diary studies. However, with this audio method there was some opportunity to evaluate such unattributed IAMs.

In a majority of cases, a trigger was easily identifiable in the environment or in thoughts, and the memories were perceived to be near-instantaneous, as is observed in laboratory studies (Schlagman & Kvavilashvili, 2008). However, on several occasions there was no immediately apparent trigger, so the IAM was coded "no cue". However, on reviewing the audio a precursor was later identified in some cases. Of the 76 cases coded as "no cue", 17 IAMs (22%) were identified as almost certainly related to memories or observations several minutes (up to 20) earlier in the journey, while another 6 IAMS (8%) could reasonably be explained by comments and memories earlier in the journey (again up to 22 min earlier), leaving only 53 IAMs (70%) for which no cue could be identified.

These temporally distant cueing stimuli can be considered as primes for subsequently recalled memories and have been referred to as long-term priming of involuntary memories (Kvavilashvili & Mandler, 2004). The following examples illustrate the phenomenon: In journey 15, in memory 23 at 22 min and 39 s into the journey, the participant spontaneously recalled a conversation with a lecturer in the department about the relative workload of publishing a paper versus giving a conference presentation. This was traced back to memory 6 at 3 min 42 s, nearly 20 min earlier, where the participant had remembered his mother seeing the same lecturer on television but getting his name wrong.

In journey 14, in memory number 10, at 5 min 58 s, the participant passed a junction he would have used to visit a business client. Four minutes later (at 10 min 5 s into the journey), a chain of memories about this client manifested without any apparent cue. A shorter delay appeared in journey 10, where at 4 min 28 s a bus drove up close behind the participant, and 1.5 min later (at 5 min 50 s) he remembered complaining to the bus company about one of their buses departing early.

Table 5. Distribution of memory chain lengths and number of chains for different chain lengths.

Chain length	Number of chains of this length
1	62
2	19
3	8
4	0
5	1
6	1
Total	**91**

Characteristics of memories

The mean percentage of specific memories that occurred at a particular time and place (and did not last longer than a day) varied with a minimum of 50% to a maximum of 95%, with a mean of 76% (*SD* = 13%), which is in line with specificity rates found in other diary and laboratory studies. A full breakdown of the number of specific memories and general memories of repeated or extended events by journey is given in Table 8.

Out of 674 recorded IAMs, 134 were negative (20% of the total), and varied from a minimum of 4%, to a maximum of 39% per journey, 409 were neutral (61%)

Table 6. Number (percentage) of involuntary memories recorded in each journey as a function of reported external trigger (static vs. dynamic).

Journey number	Static *N* (%)	Dynamic *N* (%)	Total *N* (%)
1	3 (16%)	16 (84%)	19 (100%)
2	12 (40%)	18 (60%)	30 (100%)
3	8 (47%)	9 (53%)	17 (100%)
4	4 (27%)	11 (73%)	15 (100%)
5	3 (75%)	1 (25%)	4 (100%)
6	3 (18%)	14 (82%)	17 (100%)
7	5 (33%)	10 (67%)	15 (100%)
8	8 (53%)	7 (47%)	15 (100%)
9	5 (28%)	13 (72%)	18 (100%)
10	6 (86%)	1 (14%)	7 (100%)
11	3 (18%)	14 (82%)	17 (100%)
12	8 (57%)	6 (43%)	14 (100%)
13	14 (64%)	8 (36%)	22 (100%)
14	5 (24%)	16 (76%)	21 (100%)
15	4 (20%)	16 (80%)	20 (100%)
16	6 (27%)	16 (73%)	22 (100%)
17	2 (22%)	7 (78%)	9 (100%)
18	6 (38%)	10 (62%)	16 (100%)
19	6 (27%)	16 (73%)	22 (100%)
20	3 (25%)	9 (75%)	12 (100%)
Total	**114 (34%)**	**218 (66%)**	**332 (100%)**

and varied from minimum of 30% to maximum of 80% per journey, and 131 positive (19%) and varied from a minimum of 5% to a maximum of 36% per journey. A total of 80% were therefore either neutral or positive (*cf.* Schlagman et al., 2007).

Discussion

The main aim of this research was to gain new insights into the nature and frequency of IAMs in the context of repeated, low-demand habitual everyday activity such as driving. A new audio-recording method was developed and tested on the first author as a single participant who recorded his IAMs while driving a car on a pre-determined habitual route on 20 occasions. The participant also recorded any cues in the environment or thoughts that triggered the IAM and later the transcribed memories were coded for specificity and valence.

Several novel and important findings emerged. Firstly, the number of recorded IAMs was higher than reported in other studies, and more than the participant had anticipated (but see Hintzman, 2011). Secondly, the audio-diary method uniquely facilitated the breakdown of external triggers into static cues (i.e., always there) or dynamic cues (i.e., occurring on unpredictable occasions). The results showed, for the first time, that IAMs were reported more often in response to dynamic than static cues, emphasising the importance of novelty of cues in eliciting IAMs in everyday life. Thirdly, the audio-description of internal cues enabled easy identification and analysis of memory chaining process (Mace et al., 2010), and it was found that a substantial number of memories were triggered by a preceding memory rather than some other thought. Finally, this new method enabled the authors to observe and quantify instances of incidental stimuli in the environment or thoughts that were associated with subsequent recall of related IAMs providing further support for a long-term semantic to autobiographical memory priming in everyday life (Kvavilashvili & Mandler, 2004; Mace & Hidalgo, 2022; Mace & Petersen, 2020).

Table 7. Number of unique static triggers that cued one or more different memories across twenty journeys.

Unique, static triggers count	Memories cued by static trigger
30	1
11	2
8	3
3	4
1	5
1	6
1	7
1	8
Total Static Triggers: 56	**Total memories: 114**

Frequency of memories

Although previous diary studies of IAMs have reported about two to five IAMs per day (Berntsen, 1996; Mace, 2004; Schlagman & Kvavilashvili, 2008), higher frequencies have been reported when using clickers to acknowledge IAMs without reporting their content (Rasmussen & Berntsen, 2011) and experience sampling methods (Gardner & Ascoli, 2015). This variability in findings suggests that the reported frequency of IAMs may depend on the recording method used. In addition, Laughland and Kvavilashvili (2018) showed that proportionally more memories were recorded in shorter time periods (e.g., in 1-day diary) than in longer time periods (e.g., on day 1 of a 7-day diary). This so-called *diary entry rate reduction effect* has been clearly demonstrated in studies assessing IAM frequency with mechanical counters. For example, participants in the study by Rasmussen and Berntsen (2011) recorded on average 22.13 ($SD = 16.74$) IAMs over a 1-day period (see also Rasmussen et al., 2015, Study 1), while participants in a study by Branch (2023) recorded 10.40 ($SD = 12.20$) memories during a 1-hour recording period. Large standard deviations also indicate that there were participants who reported very high frequencies of IAMs in these time periods. Similarly, in a study by Kamiya (2014), student participants reported on average 12 IAMs in a short 20-minute walk along a familiar route on campus with 30% of participants reporting 19 to 30 memories, that is one or more memories per minute. Considering all these findings, it is perhaps less surprising that in the present study, 0.9 IAMs were recorded per minute during 30–40-minute audio recording sessions while driving.

There are also several possible reasons why IAM frequency was high in the present study. Firstly, the participant was a memory researcher who had a clear understanding of what was being studied and was able to attend to the IAMs and note their cues. Secondly, the audio recording method made logging the events very easy without the need of interrupting the ongoing activity.

Table 8. Number (percentage) of involuntary memories recorded in each journey as a function of type of memory (specific vs. general) reported.

Journey number	Number of memories	Number specific	Number general
1	25	20 (80%)	5 (20%)
2	43	24 (56%)	19 (44%)
3	34	29 (85%)	5 (15%)
4	29	22 (76%)	7 (24%)
5	20	19 (95%)	1 (5%)
6	33	30 (91%)	3 (9%)
7	31	25 (81%)	6 (19%)
8	34	28 (82%)	6 (18%)
9	42	35 (83%)	7 (17%)
10	19	16 (84%)	3 (16%)
11	26	24 (92%)	2 (8%)
12	28	23 (82%)	5 (18%)
13	39	28 (72%)	11 (28%)
14	32	20 (63%)	12 (37%)
15	42	21 (50%)	21 (50%)
16	44	27 (61%)	17 (39%)
17	39	23 (59%)	16 (41%)
18	37	29 (78%)	8 (22%)
19	44	30 (68%)	14 (32%)
20	33	29 (88%)	4 (12%)

This feature of the method turned out to be particularly important for recording the large number of memory chains that would not be recorded in diary studies. Indeed, participants in diary studies are instructed to record IAMs as soon as they occur, which may disrupt the process of chaining taking place. Thirdly, and perhaps most importantly, the participant was monitoring for IAMs during a highly automatic, relatively low demand activity in which he was exposed to rapidly changing environment, with multiple cues that could potentially elicit IAMs. Given that driving demands greater visual acuity, it may be one of a small number of activities where demand is low, but it requires careful observation and monitoring of the environment. As such, driving may be an optimal everyday task for observing IAMs, as it has been for mind-wandering (Charlton & Starkey, 2013; Galera et al., 2012). In this context, it is important to note that present findings concur with observations made by Hintzman (2011) who reported a large number of IAMs or "remindings" over a 2–3 day period most of which he recorded while driving or walking. Importantly, they also concur with the findings from our follow up study on 32 undergraduate students (Laughland & Kvavilashvili, 2024), who audio-recorded their IAMs during a pre-determined 30-minute campus walk, and recorded on average 7.03 IAMs ($SD = 4.92$) ranging from 1 to 20 memories, which indicates that some participants recorded one memory per 1.5–2 min even though the change of scenery and the rate of potential cues occurred at slower pace than during driving (for details see Laughland, 2017).

Static and dynamic cues

In line with previous studies of IAMs, in most cases triggers were readily identifiable, with only 11% of recorded memories being perceived as having no obvious external or internal cue (Berntsen, 1996; Kvavilashvili & Mandler, 2004; Mace, 2004; Schlagman & Kvavilashvili, 2008). By breaking down IAMs into memories that were cued by thoughts and memories that were cued by preceding memories, which could thus be reclassified as chained memories, it was found that the number of internally cued memories, compared with externally cued memories, was significantly smaller, as found by Berntsen (1998).

Importantly, the audio method uniquely allowed us to differentiate external cues as dynamic and static types. Results showed that in 15 out of 20 car journeys, the dynamic cues outweighed the static cues, and the number of dynamic cues was significantly higher than the number of static cues ($p < .001$), suggesting that familiar surroundings were less conducive to eliciting IAMs. However, when attention was drawn to the novel, or out of the ordinary stimuli, IAMs were cued.

The opportunity to distinguish static and dynamic (or novel) triggers is not generally feasible in diary studies and has not been examined in laboratory studies of IAMs. However, Berntsen et al. (2013) developed a novel method for studying involuntary episodic memories in the laboratory and demonstrated an interesting cue overload effect: sounds that were paired with one particular picture at encoding were subsequently more likely to elicit a memory of that picture than sounds that were paired with multiple pictures. It is therefore possible that static cues in our study suffered from cue-overload, as potentially they could have many memories attached to them (e.g., seeing a road sign to London's Heathrow Airport would be associated with multiple journeys to the airport on that road for holidays and business trips). Another possibility is that people may pay more attention to the novel than static cues. Although present results do not enable us to assess these explanations, the distinction of static and dynamic cues clearly merits further investigation.

Memory chaining

The large number of chained memories observed in the present study was surprising. Mace (2010) argued that this phenomenon is relatively uncommon, and estimated that approximately 15% of all naturally occurring IAMs may result in a chain of memories (Mace, 2006, 2007). This concurs with low incidence of memory chains reported in naturalistic diary studies, although this could be due to burdensome nature of writing down sequences of memories and/or the fact that the act of initiating the logging may itself break the chain. Indeed, when Mace et al. (2013) designed a diary where participants were specifically coached to be diligent in recording chains, the results showed that only 14% of IAMs were recorded as being triggered by a previous memory.

By contrast, in the present study, although the participant was not expecting to experience memory-cued

IAMs, the audio recording method allowed the examination of cues retrospectively, and it was at this later stage that the many chains became apparent. Moreover, as many as 23% of all recorded memories were chained. However, the distribution of chain lengths was remarkably consistent between the diary of Mace et al. (2013) and the present study: chain length of one, 68% vs. 69%; chain length of two, 20% vs. 21%; and chain length of three 7% vs. 9%, with a small number of longer chains in both studies.

Although the chaining phenomenon has received little attention (Mace, 2006, 2009; Mace et al., 2010), studying IAM chaining is important because it potentially gives insight into the organisation of autobiographical memory (Mace et al., 2010). A key question about chained memories is how they relate to the initial memory, and other chained memories, if the sequence continues. Mace et al. (2010) asserted that chained memories were linked conceptually (i.e., a memory of one holiday may trigger memory of another holiday) in about 80% of cases, whereas just 20% were linked by time (e.g., a memory close in time to that holiday, such as an incident at work on return from the holiday). This was explained by memory chains reflecting the automatic spread of activation in the memory system that is organised by common themes rather than time periods.

Priming of involuntary autobiographical memories by preceding events

Perhaps the most interesting and potentially important finding that emerged from the present study involves the serendipitous discovery at the data transcription and coding stage that the recall of memories was associated not only with easily identifiable triggers (external or internal) at the time of recall, but also with incidental stimuli and thoughts encountered or experienced several seconds or even minutes before the memory came to mind. In particular, there were delays of between 2 and 20 min between a possible priming event and a later IAM that were convincingly traceable due to a strong association between them (*cf.* Kvavilashvili & Mandler, 2004, who were able to trace back priming events for involuntary semantic memories or mind-pops). For example, in journey 1, memory number 20 offered an interesting example of this long-term priming: the participant had been at a music concert the previous evening with a friend, noted at 16 min 2 s into the journey. Just over a minute later, at 17 min 23 s, he thought about a BBC radio recording event he attended, with no apparent cue. However, on playback and analysis, the friend at the concert also attends these radio recordings and the participant often sees him there. Therefore, it is likely that the activation of the initial memory of music concert with a friend primed and reactivated several other memories of similar events with the same friend so that sometime later one of those memories was recalled seemingly with no cue.

The audio analysis could be applied also to IAMs with an identifiable trigger, to see if they too can be traced back to some precursor. For example, following a memory about one of the computer consultancy clients, there was a later memory about that client cued externally, but it is possible that the second memory would not have occurred if not previously primed by the first. Overall, our preliminary findings seem to suggest that both components may be needed to elicit IAMs in everyday life – the earlier prime to activate a memory representation, and then some incidental cue that tips it over a threshold (for evidence from laboratory studies of semantic to autobiographical memory priming, see Mace et al., 2023; Mace & Hidalgo, 2022; Mace & Kruchten, 2023).

Theoretical implications

Our results in relation to static and dynamic cues, memory chaining and long-term priming have implications for current theories of autobiographical memory. For example, Conway's influential model of autobiographical memory (Conway & Pleydell-Pearce, 2000) proposes that memories are organised into a hierarchical structure, with lifetime periods at the top then, within each lifetime period, general events and then a more specific pool of event specific knowledge or information at the bottom. According to this model, voluntary retrieval of memories involves activation processes that spread top down via the system starting from lifetime periods, down the hierarchy via general events and reaching the bottom layer of specific events. Conway and colleagues conducted several priming studies that provided evidence for such a top-down spreading activation process. For example, one study (Conway & Bekerian, 1987) showed that when participants were first primed by a certain life time period (final year at school), and then presented with keywords relating to an event that had occurred in that lifetime period (e.g., a trip to Italy), this resulted in faster retrieval times than when no life-time period primes were presented. These findings support the idea of memories being organised within temporally related structures with activations spreading via event representations linked to a particular lifetime period. This model suggests that chained memories would be more easily retrieved if they were temporally related. However, if a vacation while school-aged reminds one of a more recent vacation when aged 50, this type of chaining suggests memories may not be organised in lifetime periods.

The number of chains, and their length, without any apparent effort to retrieve them, appears to be more in keeping with the model of Uzer et al. (2012) who found large numbers of directly retrieved memories even in voluntary autobiographical memory experiments (i.e., participants reporting memories popping into mind with little effort in response to cue words when asked to recall memories deliberately). Therefore, Uzer et al. (2012) proposed that memory traces may not be always distributed across the temporally organised hierarchical structure but may be instead organised in more stable clusters that get activated simultaneously without top-down reconstructive processes. In line with this view, chaining examples show that it is possible to quickly retrieve a memory from a completely different lifetime period. Hence, it is possible that memory fragments at the bottom layer of autobiographical memory system cluster together based on conceptual similarity, which means that spreading of activation can go directly to other conceptually related fragments, circumventing any need for top-down processes within a particular time-period.

Another theoretically important finding relates to the demonstration of a very strong link between the cueing event and the memory (Berntsen, 1998; Mace, 2004; Schlagman et al., 2007). This raises an interesting question as to why certain memories repeat in response to the same static cue in the environment, but also why the same memory does not constantly recur in response to the same cue. For example, a motorway sign to the town of Aylesbury prompted sometimes a memory of attending a music concert there, but other times a meeting attended in the town. Similarly, road signs to the airport sometimes prompted memories of holidays, while other times of business trips, but most times no memories. Based on these intriguing findings, our working hypothesis is that for any given cue to elicit a particular memory, its representation must be pre-activated (i.e., primed) by previous exposure to certain events in one's environments or in one's thoughts. Such pre-activation of memory representation, or parts of representation, would dictate when a subsequent cue does prompt a memory and when it does not (*cf.* Mace et al., 2023; Mace & Hidalgo, 2022; Mace & Kruchten, 2023).

To date, various modes of long-term priming for IAMs have been identified. For example, Mace and colleagues have demonstrated priming of IAMs by *voluntary* recall involving prolonged reminiscing about a particular lifetime period (Mace, 2005; see also Barzykowski & Niedźwieńska, 2018), or recalling personal memories in response to cue phrases (e.g., remember a time when you were exercising) (Mace & Petersen, 2020). Results of the present study indicate that IAMs can also be primed by involuntary recall whereby a particular IAM is followed, several minutes or even hours later, by another IAM that is similar in content to the earlier IAM. Furthermore, Berntsen (2007) discussed *motivational* factors (e.g., one's current concerns) that may prime and make some memories more accessible than others (e.g., memories related to a lifetime period or a particular person). Johannessen and Berntsen (2010) specifically investigated a role of current concerns (Klinger, 1978) in relation to IAMs, and found that up to 50% IAMs, recorded by participants in a diary, were related to their *current concerns*, for example, worry about work or romantic partner (see also Ball, 2015; Mace, 2005, Study 1). These current concerns appear to sensitise participants to appropriate cues in the environment, or thoughts and result in a recall of concern related IAMs (*cf.* Ball, 2015).

However, the evidence from the present study suggests the third type of priming, namely, *accidental* encounters with incidental stimuli in the environment (or inner thoughts) that seem to activate memory representations, which may later re-surface in a form of conscious recall. Although this type of continuous activation of autobiographical memory content in response to cues was proposed by Conway (2005), it has been subjected to laboratory testing only recently by Mace and colleagues (Mace et al., 2019, 2023; Mace & Hidalgo, 2022; Mace & Kruchten, 2023; Mace & Unlu, 2020). However, until now, it has not been possible to detect this type of semantic to autobiographical memory priming in everyday life using a standard paper diary method of IAMs (but see Kvavilashvili & Mandler, 2004).

These three types of priming, and subsequent cueing of an IAM suggests a new model IAMs that should be tested experimentally. The model proposes that, at any given time, the occurrence of IAMs is a function of the interplay of various parameters such as deliberate or spontaneous recall of memories, encounters with incidental stimuli, and current concerns/motivational factors, which can all pre-activate certain memory representations. If the ongoing activity is very demanding, then no matter how highly activated or primed, the spontaneous recall of that memory representation may not take place. Conversely, if there is a very strong cue, pre-priming may not be necessary (see Figure 1). There is then an interesting question of whether both prime and cue are needed, for a spontaneous recall to occur or whether one of these factors is sufficient if it is strong enough and when participant is not engaged in a cognitively demanding task (for discussion of overlap between primes and cues see Mace & Hidalgo, 2022; Mace & Kruchten, 2023; for further discussion see Jordão & St. Jacques, 2022). This is clearly a question that needs to be assessed empirically in future naturalistic and laboratory studies of IAMs.

Methodological implications

Another major outcome was the development of a novel method of audio recording IAMs in a relatively controlled naturalistic environment, which resulted in several new insights on the nature and frequency of IAMs that would not have been obtained with either paper or smartphone diaries. Some of the triggers and primes were found by verbal exploration (thinking aloud) by the participant while driving, but others were picked up in later transcription of the audio. Thus, key features of audio recording and vocalising the thought processes was the ability of this new method to explore, for the first time, the role of static and dynamic cues in eliciting IAMs, quantify many memory chains and pick up primes to the "no cue"

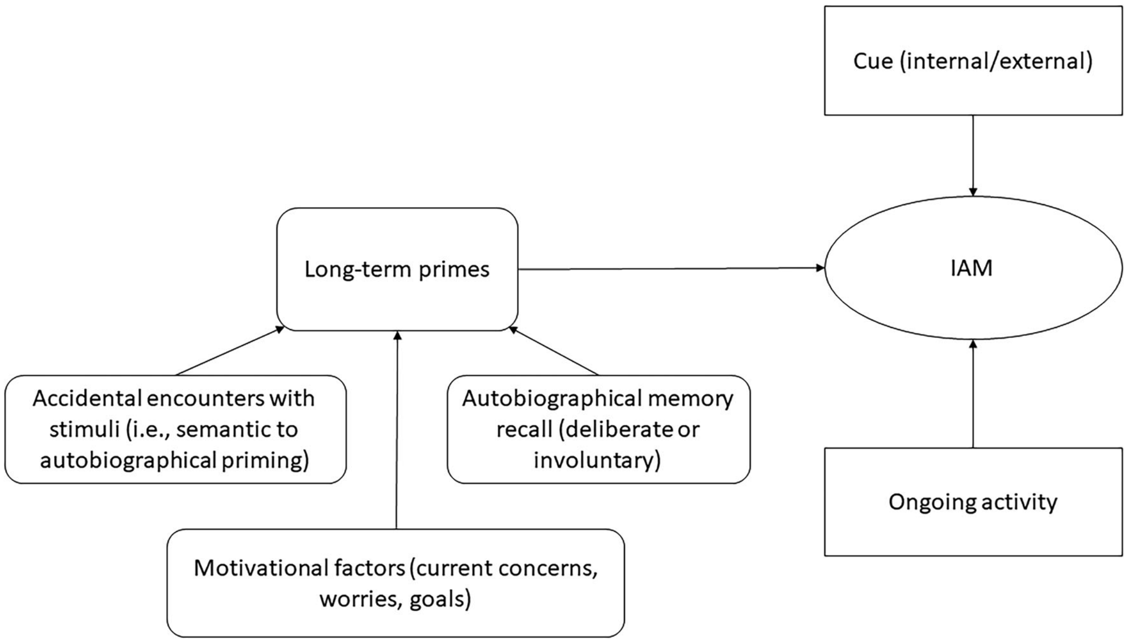

Figure 1. A proposed model depicting key variables contributing to the occurrence of involuntary autobiographical memory at a particular time and place. The model distinguishes between immediate (triggers, ongoing activity) and more distal factors (long-term priming in the form of incidental stimuli, goals/ current concerns and recalling events from one's past) in eliciting involuntary autobiographical memories.

memories that occurred a few, or many minutes before. This was not something that could have been achieved in written logs of the memories, and as such provided a richer dataset. An interesting avenue for future research would be to expand this method for studying other spontaneous cue-driven phenomena such as involuntary future thinking (Cole & Kvavilashvili, 2021).

Study limitations and future directions

There are some limitations. One is reactivity – the participant was aware of what was being measured (French & Sutton, 2010), which could affect the frequency and types of IAMs that were recalled during the journeys. For example, Vannucci et al. (2014) found that more memories were reported by participants who knew that IAMs were studied than those who did not know. However, this effect was present only when participants were stopped by the researcher, but not when participants stopped themselves to report IAMs, indicating that these participants may have lacked meta-awareness to detect some IAMs during the task. Given that the participant in the present study used the self-caught method (as in all the other paper diary studies), it is less likely that frequency of recordings was artificially enhanced, if anything, it is possible that fewer IAMs were recorded than what was actually experienced (although, relatively short periods of monitoring should have facilitated more accurate recording compared to diary studies that require monitoring over several days or weeks). In addition, although some memory characteristics such as specificity and rehearsal may be affected by participants' knowledge that IAMs are being studied (Vannucci et al., 2014), the characteristics of IAMS recorded in the present study in terms of memory specificity, external cues and memory valence were all in line with findings reported in previous diary studies of IAMs (Berntsen, 1996, 1998; Laughland & Kvavilashvili, 2018; Schlagman & Kvavilashvili, 2008).

Secondly, while there is a precedent for researchers collecting data on themselves (Berntsen, 2009; Conway et al., 1996; Kvavilashvili & Mandler, 2004; Linton, 1986; Wagenaar, 1986; see Sotgiu, 2021 for a review of such single case studies) as a precursor to novel research in cognitive psychology, the study needs to be extended to other participants. It may be that the participant is an outlier, and that most drivers do not experience one memory per minute or are at least not aware that they do. However, having participants audio record their IAMs while driving may involve ethical issues about participants' safety. Therefore, further development of the audio recording method should be considered for IAMs, perhaps with participants walking, rather than driving, a familiar route, or as a vehicle passenger on a familiar route (Kamiya, 2014). It would be also interesting to test the audio diary method by asking participants to keep an audio diary for 3–4 h in a naturalistic setting, although privacy issues would have to be addressed.

We also anticipate that the method could be refined and applied more broadly. For example, it may be useful to research on driving as another approach to studying distracted driving, to ascertain what are people thinking about when driving. Are their thoughts and attention localised inside the car rather than focussed outside? Are the cues (or distractions) external to the vehicle? And how does familiarity with the route affect the number and types of memories? (for initial answers to these questions in relation to mind-wandering see Burdett et al., 2018, 2019). Moreover, static and dynamic cues may remind us of negative events and thereby help us to avoid dangerous situations (Baumeister et al., 2001; Schank, 1999). This seems relevant to driving (e.g., remembering a previous hazard or accident), and new insights into the mechanisms of IAM production while driving may lead to improved driving safety.

Conclusion

In conclusion, this method shows considerable promise for recording and analysing IAMs, beyond situations where writing or typing is not feasible. This research provides further evidence that the rate of IAMs is more frequent than suggested by earlier measurements and self-assessments (but see Gardner & Ascoli, 2015; Hintzman, 2011; Kamiya, 2014). Importantly, analyses of the audio playback revealed that priming events, occurring even a few minutes earlier, were not recalled when trying to describe the IAM (see also Kvavilashvili & Mandler, 2004). In 2010, Mace concluded that priming in IAM was not fully understood. Although significant advances have been made recently in studying semantic to autobiographical memory priming in the laboratory by Mace and colleagues, it is a difficult phenomenon to study in everyday life. However, semantic to autobiographical and other forms of priming clearly warrant further, more detailed and systematic research to enhance our theoretical understanding of mechanisms involved in recalling IAMs. It will be important to use both laboratory and naturalistic methods of recording IAMs while also examining and/or controlling for other variables such as external triggers, current concerns and ongoing task demands. Further, the recently developed laboratory methods for IAMs might also be extended by incorporating concurrent audio recording to study effects of incidental priming and time delays between a prime and a cue under more controlled conditions (e.g., Mace & Hidalgo, 2022; Mace & Kruchten, 2023).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

All the data except the contents of recorded memories are presented in the paper. The contents of memories are not available for sharing, because of the nature of the study (i.e., the participant's anonymity cannot be protected). The SPSS data file with the details of 20 car journeys presented in tables of this paper is also available from the corresponding author upon request.

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