Actively Constructed Cues for Episodic Recall

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Lifelogging technologies promise to help support total recall of our lives through automated capture of large volumes of digital content. However, research has shown that lifelogging brings less benefit for memory than anticipated. To address this we report a diary study with 12 participants provided with tools for capturing cues through photos, doodles, moods, diaries, audio, and video recordings to support recall of their meaningful daily events. Findings indicate that cues capture both external and internal content for both recall and reflection, and the different impact of cues' content and modalities: people and objects captured through photo, or audio/video of environment support better recall of environment context, while feelings were better recalled by doodle, emoticon, diary or audio/video of one's voice. We conclude with three design implications for materializing both external and internal cues and the active construction of the latter, new interfaces for more meaningful spatio-temporal cues, and for integrating the various multimodal cues' content.

Actively constructed cues. Episodic memory. Recall. Reflection. Doodle

1.INTRODUCTION

Personal digital technologies now make it feasible for people to archive their entire lives [63]. Lifelogging technologies such as mobile apps and wearable devices assume that automatic capture of digital content will support *total recall*: retrieving and accessing any detail of our life whenever desired [16,22,41]. This thesis has been challenged by findings suggesting that lifelogging brings less benefit for memory than anticipated [35,64], and that information retrieval from large digital life archives is often poor [35,71]. These negative results have been attributed to multiple factors including the cost of curation, limited integration of digital archives with everyday life, and restricted focus on recollection and retrieval rather than memory functions such as reflection and reminiscing [50]. A key issue with the lifelogging approach is that its technology-driven focus is insufficiently grounded in psychology [63,71]. In particular, lifelogging fails to incorporate two critical facets of human autobiographical memory. Memory is *selective*, so people don't remember everything. It is also *reconstructive*, involving regeneration of past experiences from partial cues. Recall is best when it is mediated by active selection of meaningful cues [3,66,69]. This has led to design proposals that lifelogging systems incorporate both selection and cuing mechanisms [50,71].

This study uses these theoretical and design insights to explore lifelogging technologies, while taking a new approach to the study of cues. Despite the fact that recall is the last of the three stages of memory (beside encoding and storage), most research on memory cues has looked at cues only during recall. Rather than prioritizing cued recall, we started the exploration of cues from its very beginning: at the encoding stage. In this way, we wanted to sensitize participants towards the question of what makes a good cue, not just after, but *before it is captured*. As we know little about how people manually construct cues to aid recall of memorable daily events, we provided participants with a wide range of methods for creating cues, including photo, audio, video, drawing, text, and emotion tags. This allowed us to explore *what* people aimed to remember as well as *how* they remembered it.

More specifically, we examined which events people wanted to remember, their motivation for constructing memory cues, preferred cue types, and the impact of different cues on recall. Understanding this can inform the design of lifelogging technologies to better support memory functions.

Our approach to the exploration of cueing process focuses on *actively captured and constructed cues* for remembering everyday events. We define cues as active (manual) records taken to prompt recall of daily events that people would like to remember. Their content is either externally available (captured as it is), or explicitly constructed, for example through hand drawings or recording one's voice. We ran a diary study with 12 participants to address the following questions:

- What types of *meaningful daily events* do people capture? Which *qualities* set such events apart?
- What *modality* do people prefer for actively constructed cues? Is there a preference for capturing photos, drawings, text, or sound-based cues?
- What *content* of daily events gets captured by such cues? Is there a preference for objects, people, places, time, emotions, or thoughts?
- Do actively constructed cues *help* recall?

Our contributions are threefold: we advance empirical exploration of actively constructed cues, we show the specific benefit of different cues' content and modality for episodic recall, and highlight three design implications including tools for materializing both external and internal cues with the active construction of the latter for both recall and reflection, new interfaces for more meaningful spatio-temporal cues, and for integrating the various multimodal cues' content.

2. RELATED WORK

We draw from theoretical perspectives and empirical findings in memory technologies in HCI and memory research more broadly.

2.1 Memory Cues for Episodic Recall in HCI

A rich body of HCI work on memory technologies has focused on memory cues [28,29]. Most HCI work on episodic memories has involved diary studies focused on automatic or manual capture of existing content. In an early study, Eldridge and colleagues [19] investigated automatically constructed visual and textual cues. from locations tracked by wearable badges. Recordings of 3 participants' activities over 5 days resulted in two cue modalities: videos from third person perspective, and automatic text-based descriptions of activities, time, location and people. The impact on recall indicated the stronger benefit of videos [19].

Another body of work has shown SenseCam's benefits for strengthening episodic memories, particularly for people with memory impairment [27]. Sensecam is a sensor driven camera that takes pictures in response to movement or changes in light and temperature. Lee and Dey [41] ran a diary study with 9 participants (5 with memory impairments) wearing SenseCam for automatic capturing of daily experiences which they would like to later remember. Findings show that the best cues possessed memorability, distinctiveness and self-relevance. The content of the best cues was analysed along four features, which in decreasing order of frequency were *people, actions, objects, and places.* Sellen et al. [64] also explored the impact of manually and automatically captured photos on cued recall at three time intervals. Their findings also showed that compared to manually captured, the automatically captured SenseCam photos, were better cues for event recognition and recall [64]. Additional work on memory cues captured by wearable cameras has looked at how their large number of daily photos could be integrated in short videos which users perceive as more attractive and stimulating, providing more vivid and accessible experience while being less cognitively demanding [40].In contrast to the most studies which have focused on visual cues, a limited number of studies have compared cue modalities [30]. Carter and Mankoff conducted a diary study with 7 participants capturing information during a one-day festival, through photos, audio recordings and tangible objects [10]. The comparison of the benefits for recall suggested the superiority of photos. Their findings also indicate that cues capturing external world such as photos, audio, and tangible objects could be improved though annotations.

In a diary study of 10 families capturing holiday mementos, Dib et al [15] explored the benefits of sonic souvenirs in family reminiscence. In contrast to photos, sound cues tend to be more diverse, familial, creative, authentic, and harder to interpret. They identified two types of cues: ambient sounds capturing the essence of a place such as nature-sounds or candid fragments of conversation; and constructed content for staged performances.

Other modalities of automatically constructed cues include geo-locational cues [35]; digital media cues, e.g., calendars and email [19,44]; biofeedback cues, e.g., heart rate and galvanic skin response [59], tangible objects cues [28], and kinaesthetic cues [68]. However this work has tended to overlook the distinction between automatic and manually constructed cues (noticeable exceptions include [32,57]). This distinction goes deeper than the mere capture process. It extends to the distinction between the readily available material to be captured as it is, and the material that needs to be constructed by participants. For example, SenseCam photos can be captured manually or automatically, but unless people purposefully manipulate artifacts to construct the composition, they tend to capture the available content just as it is. Audio recordings of ambient sound capture content available in the environment, but recording one's own voice requires content construction.

Tangible technologies have been also explored for capturing everyday experiences in the home and how they could cue mundane memorable experiences [45,46], or prompt recall in familial settings [34,65] of both past and future events [49].There is also a wealth of research on mobile

apps such as those supporting diary or journaling practices which explicitly capture memory cues [20,31], or those implicitly capturing fragments of everyday experiences which could be used to prompt recall and reflection on such experiences especially in health domain [26,53].

More recent work has started to explore how memory cues can be not only automatically captured, but also crafted in the form of scrapboxes [61], hand-made toys [56] or 3D printed flavours [23,24,25].

2.2 Cues in Autobiographical Memory Research

Life events are important components of theoretical models of autobiographical memory [9,12,42]. They can be cued by event characteristics such as people, places, emotions [12,42], or objects [6]. Studies of episodic memory have been performed in experimental settings or diary studies where participants record self-relevant cues of their daily events occurring in the wild. Such diary studies showed the efficiency of single cues, in decreasing order, facilitated by *what-, who-, where-* and *when-cues* [70], or that *what-* and *where-cues,* followed *who-cues,* are the most efficient, while *when-cues* are the least [9]. Outcomes also showed that remembered events tend to be salient, distinctive, and emotionally positive [42].

Several theoretical perspectives support the importance of participants' involvement in the construction of cues agreeing that self-constructed material is better remembered than readily available one. Slamecka and Graf's *generation effect* [66] states that verbal cues created by people support better recall than cues given to them, arguably because deeper information processing, and increased cognitive effort leading to stronger connection of cued content with previous memories.

Building on similar arguments, *the elaborate encoding theory* states that the more unusual and meaningful associations are being made at the time of encoding, the more successful the retrieval [3]. Elaborate encoding and generation effect are also consistent with Tulving's *encoding specificity principle* [69], according to which the processes of encoding the information to be memorized influence what is being stored and recalled. The generation effect of verbal cues extends to pictorial material such as hand-drawings of objects and scenes [51]. It also extends to self-performed actions and gestures that are better remembered than observed one [43], suggesting the importance of the body for both memory and cognition. Despite the consensus surrounding the importance of active encoding this has not been extensively examined in the context of cues for digitally mediated autobiographical memory. This is what our current study explores.

3. METHOD

We recruited a convenience sample of 12 participants, 10 male and 2 female (mean age 23, range 21-28). All participants were smartphone users and familiar with Android OS, but with limited experience of lifelogging technologies. We selected this age group to explore the value of cues, rather than elderly or memory-impaired people. If young people's memory recall can benefit from self-constructed cues, then such cues could benefit everybody (see [64] for a similar argument).

We conducted a one week-long diary study consisting of three stages. In the first stage, we introduced the study and provided participants with Android smart phones with built-in cameras for photo and video capture. We gave all participants the same dedicated phone to ensure that they all had the same cue generation and retrieval tools. The phones were also pre-installed with three applications supporting the capture and construction of alternative cue modalities: *Picasso* for finger drawing, *SmartVoice Recorder* for sound and voice recording, and *AIRS* [48] for capturing mood selection through emoticons, and for describing events through text annotations following a diary format. The fourth application: *AnyTimer* was installed for sending participants daily reminders about the study.

In the second stage, participants were instructed to capture cues of *meaningful daily events* that they would like to remember. We asked them to experiment with the full range of cuing tools we provided them.

The third stage consisted of semi-structured interviews conducted twice during the study, i.e., midweek, and at the end of the week. During the interviews, we asked participants without being given cues, to describe the most meaningful events they had experienced over the last few days, i.e., free recall, and to rate the emotional intensity on a 9-point scale from extremely negative (-4) to extremely positive (+4) events. From the total cues, 50% were randomly selected for cued recall, i.e., at least two for each day, drawing from various modalities. For each cue, we explored the memories they cue, their content and modality, the rationale for capturing and constructing them, and for the chosen modality. In the final interview, we also asked participants about their preferences for different cue modalities, and the advantages and limitations of the different cueing tools.

The study generated over 18 hours of audio recordings. Interviews were transcribed and analysed through inductive techniques of coding and thematic analysis. A conceptual framework developed from prior literature provided initial categories such as cue modalities [19,27,41] and cue types [6,12,42]. These were refined as new

codes emerged from the data, e.g., types of daily events, doodle modality, *why-cues,* and multiple heterogenous cues. The qualitative analysis was integrated with quantitative data involving mostly descriptive statistics within the identified themes, and inferential statistics which were mostly used to explore cues' impact on recall.

The analysis integrated quantitative and qualitative data. The former involved descriptive and inferential statistics, and the latter involved thematic analysis. The initial framework included daily memorable events, cue format and cue content, which were extended to integrate cue modality and content, and multiple heterogenous cues. The inferential statistics were mostly used to explore cues' impact on recall.

Preliminary findings from this study have been previously reported [57], and the current paper extends them with larger sample of participants and more detailed findings. The study has received ethics approval as per University requirements.

4. FINDINGS

4.1 Types of Events To-be-Remembered

Participants captured a total of 250 cues (Mean = 22) for recording 157 events to-be-remembered (Mean = 16). The timing of the study allowed the capture of a mix of daily events, including mundane and recreational ones such as trips and holidays, as well as Christmas preparations. Based on participants recall and cues' content, these events can be mapped into three domains: two specific ones, i.e., work and leisure, and a meta-domain, i.e., emotions and their processing. Together they provide two major benefits: *recollection* of leisure and work activities, and *reflection* on significant emotional events (Table 1).

Table 1: *Types of events, domains, and memory benefits*

Domain	Events (%)	Memory benefit
Leisure (Specific)	49%	Recollection
Work (Specific)	27%	Recollection
Emotions (Meta)	24%	Reflection

Findings show limited evidence for cues supporting other potential memory functions such as reminiscing, remembering intentions and retrieving [63]. Consistent with prior work [12,32], almost two thirds of the events involve positive affect, and negative affect about a third. The most common events were *leisure events* including recreational activities such as taking a lunch break at work, cooking dinner at home, watching television at the end of the day, going out on a Friday night, enjoying hobbies, taking short weekend trips, going on holidays, or engaging in Christmas preparation activities.

All leisure events were described in terms of positive emotions, and half of these were intense emotions (+3 and +4). For example, P6 describes downloading a new, free game release one Saturday evening, or the weekly rehearsal of his band in which he plays drums, while P9 and P10 describe a holiday overseas. Leisure events may be cyclic, but follow a less frequent rhythm standing out as distinctive when compared with mundane, work-related ones:

"Saturday I was hiking with my friend. It was fun: +3. That's the picture [of a painting] in the bedroom in my friend's house. I'd just woken up after a good night sleep which I hadn't done for that week because I'd been busy. I took the photo as soon as I woke up" [P5].

Next most common were *work events* including training, learning, researching, or teaching, as well as household chores such as cleaning and shopping. While most work events (75%) are experienced through low arousal emotions, e.g., boredom, the most memorable ones involve high positive emotions, such as achievement and pride for work well done: *"[The most memorable event was] my first phonics lesson [with only a day to prepare]. It went really well and I was really happy: +4. This is our guidebook for the year"* [P1].

Also common were *reflection activities* - which are rather different. They capture participants' feelings and thoughts *about* an event, including participants' inferences about the causes of feelings or emotional appraisal [1,38]. Unlike leisure and work events, most reflection events (80%) express negative emotions such as sadness, stress, or frustration: *"I'd got back in the evening and locked myself out of my room […] The porter had to come and let me in [I felt] -3. When I got back, I saw my keys on the desk and took a photo; I don't like drawing as I'm not very good."* [P4].

4.2 Cue Modalities

By experimenting with tools we provided, participants developed preferences for less familiar tools, appropriating them in unforeseen ways. This contrasts with findings documenting people's reliance on familiar capture tools [15]. As anticipated, photos are most commonly used, confirming other work showing their value for recall [27,35,41,64]. However, the second most common is doodles - which is surprising (Table 2). We now explore participants' motivation for cue modalities.

Table 2: *Cue types (% from total number of cues)*

Photo	Doodle	Diary	Mood	Audio	Video	Total
63%	17%	10%	5%	4%	1%	100%

Motivation for Capturing Different Cue Modalities
We identified two distinct yet conflicting motivations for cues. These relate to the *availability* of the content, and the creative *effort* needed to construct unavailable content. For certain types of memories, environmental triggers are readily available, and cues can be effortlessly captured through photos/audio/video recordings of the surroundings. In contrast, mental events, be them past, future, or imagined are not directly available from photos, video, or audio and so their cues need to be actively created before they can be captured. For example, while reminiscing about the past, P1 could not capture any external visual or auditory event, so she needed to create something new: the cheerleader bow identified as an evocative cue (Figure 1). Given the creative aspects involved in the creation of cues, and particularly doodles, the findings below provide visual illustrations as reproductions of original doodles.

The perceived higher cost for generating such cues is reflected in their lower numbers. The preference for cue modalities also relates to type of events (Table 3). Interesting is that photos are seldom used for reflection on mental events, whereas mood and doodles are preferred (as well as the 3 videos).

"*I was getting nostalgic and started to look at old cheerleading pictures and videos. I was a bit sad. [Why did you choose to make a doodle of a bow?] Because it was easier to draw than to take a picture of something that wasn't actually happening*" [P1].

Figure 1: *Doodle of absent object for an emotional memory*

Table 3: *Cues generated for different types of events*

	Photo	Doodle	Diary	Mood	Audio	Video
Leisure	58%	55%	71%	23%	55%	33%
Work	40%	7%	0%	15%	25%	0%
Reflection	2%	38%	29%	62%	20%	67%
Total	100%	100%	100%	100%	100%	100%

Capturing Externally Available Content
Photos are the highly preferred cue for available content as their capture is low cost, simple, familiar, and quick: *"the simplest thing to do, I didn't want to spend a lot of time doing it"* [P3]. Photos also provide simultaneous access to the largest number of memory categories, such as objects, activities, and places [41]: *"The photo is the first because you need to capture the [present] moment"* [P8]. As a result, as P10 noted: "*photographs make it a lot more vivid"* having a strong evocative power of "*transporting you directly back"* [P2].

Another modality is aural cues capturing recordings of ambient sounds. Although less frequent, they provide strong evocative power, confirming the value of sonic souvenirs for capturing iconic scenes and their atmosphere [15]: "*Sound could be even more vivid than photos*. *[This one is] walking through Ghent market because you can hear French and Dutch. That could have been inside the restaurant. […] Now I can physically remember being sat. You need the voice and sound to remind you of ambience and everything else associated with that"* [P10]. Such photos and aural recordings can only capture what is present here and now: *"the activity at the time"* [P6] offering limited rationale of their capture.

Constructing Externally Unavailable Content
Cue content is harder for unavailable content, being constructed through doodle, mood, and diary applications. A significant finding is the prevalence of doodles which consist of representational drawings (40%), textual labels of emotional states (29%), abstract drawings (18%) or combinations of these three basic types (13%) (Figure 2).

Figure 2: *Doodle types: Representational drawing (let), Text labelling emotions (middle), Abstract drawing (right)*

But what motivates people to use doodles when they want to invoke mental content? Key reasons involve creativity and self-expression, as doodles allow for non-verbal depiction of self-relevant concepts and emotions: "*I like the creative part of doodling with the colors. I find it quite relaxing and fun […] I often have like a keyword or something that describes what I'm doing, and then I like to draw a little picture to help me remember it"* [P11].

The additional effort and skill required by doodling is noted by several participants: "*I am not very artistic, and [my doodles] weren't exactly accurate"* [P9], while others mentioned the challenge of representing visually complex activities leading them to generate word-based doodles: "*I was not sure how to represent working on coursework for my class [I didn't] know what to draw so I was just writing words*" [P3]. This suggests that doodles are appropriated for generating textual content, similar to diary entries. Because of their simplicity, diary and mood apps are the next preferred tools for generating mental cue content: "*it is nice, as it is easier to do*" [P3]. Unlike photos, textual cues capture the inner world of feelings and thoughts, through labels of emotions, and reflections on an event's significance. Thus, these types of cues allow easy reconstruction of their meaning when later revisited: "*sometimes the photo doesn't always relate to memory as well as I thought it might do. For example, the picture at the pub*

doesn't say anything about why I was taking that picture" [P7]. This quote advances the important thesis that photos' content is specific and discrete, failing to express the events' underlying meaning.

Our findings also suggest that photos' content requires additional emotional sense-making, that can be enabled by mood selections and diary entries. For example, two participants articulated the relationship between their emotions and the significance of the event, with emotions becoming the organizing principle for capturing cues: *"I always select the mood I was in, then the most appropriate method to capture it [often] photos, followed by text [describing the reason for taking the photo]"* [P7]. Another participant noted the importance of capturing visual and textual cues for integrating context and meaning: "*I used photos the most, trying to do a mood [after] every photo"* [P8]. These quotes confirm theoretical models of autobiographical memory and its emotional organization [42] highlighting the need for simultaneous capture of context and meaning. Diary entries provide richer information by blending mood selection and brief textual statements of an event: "*I liked diary because it remembers what you did, in what order and when"* [P9]. This suggests that moods and diaries facilitate emotional meaning; by describing the meaning of the event, or the rationale for capturing the cue, they fill in the semantic layer lacking in photos.

Another modality for content construction is video. When a significant, achievement-related event cannot be captured, a follow up summary video can become a cue: "*I would have liked to video some of our teaching classes but I couldn't do that [instead] we did a video with how we thought it went after that"* [P1]. Such cues however are less used as people may dislike hearing their own voice, and are less inclined to put in the effort required for impression management: "*It took too long to prepare and I deleted the first attempt because I didn't know what to say half way through"* [P4].

4.3 Cue Contents

We employed a coding scheme informed by theories of autobiographical memory [6,9,12,42] to capture the following categories of cue: Objects, People, Feelings, Thoughts, Places and Time. The percentages of cues capturing these categories are: 46% Objects, 42% Places, 19% Feelings, 15% People, 11% Time, and 2% Thoughts. The largest percentages of cues capture Objects or Places, confirming the value of events/actions/objects and places [6,7,41,59], or as *what*- and *where*-cues [9]. A striking finding is the limited number of cues capturing People, which contrasts with Wagenaar's [70] and Burt's [9] findings. Another important finding is the larger percentage of cues capturing Feelings, which confirms the importance of emotional events in organizing and cueing retrieval [1,12,42,59]. Interesting is the prevalence of Feelings in reflection activities (Table 4).

Table 4: *Content categories percentages in event types*

	Objects	People	Places	Time	Feelings	Thoughts
Leisure	62%	66%	66%	82%	45%	60%
Work	34%	23%	32%	9%	14%	20%
Reflection	4%	11%	2%	9%	41%	20%
Total	100%	100%	100%	100%	100%	100%

4.4 Types of Cues: Modality and Content

We now discuss five basic cue types emerging from the findings, which integrate categories of content described earlier with specific modalities supported by the capturing tools (Table 5). These cue types are *what, where, why, who* and *when.*

Table 5: *Categories of cues content across modalities*

	Objects	People	Places	Time	Feelings	Thoughts
Photo	80%	76%	88%	75%	21%	20%
Doodle	18%	5%	3%	0%	26%	20%
Diary	2%	3%	6%	11%	28%	40%
Mood	-	-	1%	0%	17%	-
Audio	-	8%	1%	7%	6%	20%
Video	-	8%	2%	7%	2%	-
Total	100%	100%	100%	100%	100%	100%

What-Cues

We define *what-cues* as cues that describe events and related activities. Our findings show that these are external cues capturing leisure- or work-related events, mostly through photos and doodles featuring Objects. Although prior work has identified the importance of objects [41], there is currently little understanding of the qualities of such objects that make them appropriate cues. Our findings indicate that these 'primary objects' tend to be close-up shots, with limited contextual information (e.g., regarding the place of the event). Our results also allow us to distinguish between three distinct classes of primary objects: *instrumental, outcome, and iconic*.

Two types of primary objects relate directly to human activities: instrumental and outcome. *Instrumental objects* are key for the completion of activities, including drums for playing, guidebook for teaching preparation, or books for learning. *Outcome objects* capture the result of an activity, e.g., completed assignments, household chores, or cooked meals, i.e., cakes. The third type does not relate to activities, as *iconic* objects are decorative objects with the power of cueing an entire event, such as paintings, commemorative plaques, or artists' signatures: "*Each room was designed by a different artist who'd drawn something [It] was quite unique, helping me remember the layout of the room; adding a bit of a tale to tell"* [P10].

Figure 3: *Doodles capturing primary Objects: Instrumental (left), Outcome (middle), and Iconic (right)*

The same categories of primary objects have also emerged in doodles, albeit through a more elaborated encoding. An example of instrumental objects is luggage and airplane at start of an overseas holiday which are summarized into one drawing (Figure 3 left): "*I struggled to draw a train going to a plane and that represented the bags being boarded on the plane*" [P9]. Unlike photos, outcome objects in doodles capture representations of concepts lacking physical manifestation: *"During phonics class we went outside on a treasure hunt of words, and children had to recognize the words by their spelling […] cat was the most popular and successful"* [P1] (Figure 3 middle). An interesting finding is the iconic objects such as Christmas trees, captured through doodles' representational drawings (Figure 3 right). This is important as iconic objects tend to capture an abstract average of the members of a category, and prototypical objects may be difficult to find in the real world. Doodles however, allow the materialization of conceptual prototypes as described by theories of categorization [37].

Where-Cues

We define *where-cues* as cues describing the event's physical environment. Findings show that they are external cues capturing the environment of leisure- or work-related events. Their preferred modality is photos of Places and Objects, and to a lesser extent audio and video recording of ambience. *Where-cues* captured by photos depict a mixture of indoor, outdoor urban and outdoor natural environments. Unlike *what-cues* capturing Objects related to event's activity, the ones in *where-cues*, which we call *secondary Objects,* depict event's spatial layout, e.g., walls, windows and furniture for indoor spaces, buildings and landscapes for outdoor spaces.

An important finding is that Places are not described in terms of geographic locations but as containers where the rest of the categories are glued together, as reflected by the correlations between the recall scores for the following categories: Place, secondary Objects, bystander People, and Time through daylight information ($r(248) > 0.18$, $p < .05$).

Recalling such a memorable Place has a strong experiential quality, which we describe as the *affective atmosphere* of the place: "*Christmas markets on Friday evening. Felt extremely positive […] It's got fairy lights, is Christmassy […] We stopped to eat: a good time to take photo"* [P9].

While Feelings are not explicitly captured in *where-cues*, they did emerge in the cued recall. The best modality for capturing the affective atmosphere was video recordings of the ambience, like in a video of Christmas evening in Brussels's Grand Plaza capturing dancing lights on gothic buildings, synchronized with carol music: *"this is my favourite video [humming along to the music]. It makes me very excited and happy because I actually remember being there"* [P9].

Why-Cues

We define this new type of cue as *why-cues* that capture emotions related to an event and its personal significance. Unlike the external cues described above which support factual recollection, *why-cues* are internal cues capturing emotions and thoughts to support reflection (see Table 1 and 4). *Why-cues* capture two types of content: discrete emotions and the sense-making process, in both pictorial and textual forms through diary entries, mood selections and doodles.

Emoticons are extensively used to label feelings by either selecting or doodling them. Discrete emotional states are also captured through colors and abstract shapes: "*I was very stressed; and it was raining, the dots represent the rain"* [P1] (Figure 2 right). Textual labels of discrete emotions are captured through either doodled text (Figure 2 middle) or diary entries, e.g., "happy". Feelings in diary entries are often accompanied by textual descriptions. The sense-making for processing the meaning of an event is mostly textual, extending diary descriptions with elements of causal thinking. Indeed, *why-cues* capture simultaneously Feelings and Thoughts ($r(248) = .28$, $p < .01$), providing evidence of the sense-making process. With respect to emotional valence, most *why-cues* capture positive emotions (70%). While leisure- and work-events are predominantly positive, reflection tends to capture and focus on negative emotions. Another significant outcome is the preferential use of doodles in sense-making, as most doodles (85%) cue recall of negative emotions. It is likely that emotions are better expressed through drawings, i.e., sharper angles and crossed lines (Figure 2 right).

Why-cues are also captured through a small number of aural cues. Interestingly, we found evidence for two new types of sound cues capturing recordings of one's voice, akin to explanatory narratives, which extend findings on sonic souvenirs of ambient sound [15]. *Emotional snippets* are short, 2-4 seconds audio recordings of an intense emotion, such as: "*Never, ever, ever, ever [emphasized]"*, which cue recall of the frustration with a teaching session: *"I have never*

been covered in so much glue [and] don't ever want to teach reception class [as] I didn't feel like I was being a teacher [but] a mum" [P1]. *Breaks for taking stock* consist of forward looking audio or video recordings (5-30 sec.) summarizing what has been accomplished so far: "*Feeling elated after just handing in job resignation. Starting new job on Monday!"* [P10].

Who-Cues
Who-cues capture people participating in an event. We identified three equally represented categories: self, friends and bystanders. While friends and bystanders are captured in contexts where emotions are displayed or shared, self is also captured for the purpose of self-reflection. Self is explicitly captured through selfies photos (70%), and audio/video recordings (30%), supporting either the celebration of achievements or self-reflection. Friends are captured through photos in leisure and work settings, while bystanders are captured in public indoor or outdoor places, through a mixture of photos and audio/video recordings.

In terms of emotional valence, most cues capturing friends or bystanders (86%) focus on positive emotions, while those capturing self, on both positive and negative ones. It appears that bystanders are important for the affective atmosphere of a public space. Negative emotions in cues capturing self may relate to the value of such cues for self-reflection where negative feelings can be better triggers for reflection. Besides the limited number of *who-cues,* another striking outcome is that People are captured not so much in relation to activities (represented by Objects in *what-cues*) but in relation to Feelings (captured by *why-cues*). Cues capturing People also capture Feelings experienced by oneself or shared with others ($r(248)= .15$, $p < .05$).

When-Cues
When-cues capture the temporal context of an event. It is the least captured cue, confirming its limited value in recall [9,70]. *When-cues* capture mostly the temporal context of leisure events in photos. An important outcome is that Time is not captured in its traditional timestamp format of dates and hours. Instead, our participants employ alternative ways emphasizing rhythms, chronology and intentionality of their personal events, which we call *circadian cues, annual festival cues, sequential cues* and *prospective cues*. *Circadian cues* appear in photos which capture daylight, evening or night.

During the cued recall, participants had difficulties remembering dates, yet they remembered part of days, i.e., morning, afternoon or evening. Within these temporal categories, they also identify activity intervals, typically of a couple of hours. *Annual festival cues* capture celebrations such as Christmas. They are characterized by distinct culturally defined, primary and secondary objects in photos or doodles, e.g., Christmas tree, presents, lights and decorations. *Sequential cues* capture the order of actions within longer daily events through key photos marking the end of such actions: *"I was cleaning the house for most of Saturday and took random pictures from [each] rooms"* [P6]. Other cues include actions' outcomes, interruptions and breaks. *Prospective cues* tend to be photos intended as reminders of future activities: *"[The photo of a brochure] reminds me to read that brochure"* [P6].

4.5 Multiple Heterogeneous Cues

An important outcome is the number of occasions that multiple cues were generated for capturing the same event, i.e., 24% of cues capturing 42% of events. The majority of these hybrid cues (80%) consist of pairs of two cues such as photo-mood, photo-photo, doodles-doodle, doodle-diary. We also found that over 20% of hybrid cues involve three types of cues such as photo-doodle-diary, photo-diary-audio, or photo-mood-audio. Finally, a small number (3%) of hybrid cues consist of a combination of four cues, e.g., photo-doodle-diary-video. In addition, more than two thirds of hybrid cues involve different visual, textual, and aural modalities, with hybrid visual cues, such as photo-photo or photo-video capturing long daily activities either at their critical points, or as event summaries. Interdependency between cue content has been previously suggested [64]. We computed the correlation matrix for recall scores, showing that 7 out of 15 correlations are statistically significant ($r(248) > .15$, $p< .05$, two-tailed). Preferences for interfaces integrating multimodal cues also came through from interviews: "*If they were integrated as one package that would work [for example, photos and diaries] side by side or quarters together"* [P10].

4.6 Actively Constructed Cues Impact on Recall

We now explore the effectiveness of the different types of cue content on short-term recall. For this, we compared the recall cued by available content, (e.g., photos, audio and video recordings of ambience), with the recall cued by constructed content, (e.g., doodles, mood selections, diary entries, audio and video recordings of one's voice). We assessed the richness of each recalled memory by determining how many of the content categories were recalled. Recall performance was computed by scoring 1 for each recalled content category: Objects, People, Places, Time, Feelings and Thoughts (and 0 if not recalled). The richest recall score for a cue was 6, and the poorest 0. A 2 x 6 mixed-design ANOVA, with content availability (available or constructed) as between-factor, and content category (Objects, People, Places, Time,

Feelings and Thoughts) as within-factor, revealed a main effect of content category ($F(5, 730) = 13.42$ $p < .001$, $\eta p^2 = .84$). Post-hoc analyses using Tukey's HSD indicated that Feelings were significantly better recalled than Time and Places, which were better recalled than People, Objects and Thoughts ($p < .05$). The interaction effect was also significant ($F(5, 730) = 4.71$, $p < .001$, $\eta p^2 = .31$), with Feelings being better cued by constructed content, while Objects and People by available content ($p < .05$).

We extended this analysis to explore the impact of cue modality on recall. An analysis of variance indicated a main effect of modality ($F(5,125) = 2.5$ $p < .05$, $\eta p^2 = .10$), while post-hoc tests showed that Objects are better recalled by photos and doodles, People by videos, Feelings by mood selections, and Time by mood and diary entries. With respect to doodles' impact on recall, abstract ones are the best for Feelings and Time, while representational ones are the best cues for Objects.

5. DISCUSSION AND DESIGN IMPLICATIONS

We now discuss the design implications of these findings. We aim to bridge lifelogging's memory support from recollection to reflection, and to exploit the value of elaborate encoding for the capture and construction of internal cues. For this, we discuss the need for new tools supporting active construction of non-verbal emotional content captured by internal cues, and emotional sense-making, as well as tools supporting new perspectives on externally available content. We also discuss the value of automatic detection of spatio-temporal cues captured in photos, to exploit people's preferences for capturing and recalling such content in different ways than those supported by meta-data. Finally, we address the problem of fragmented multimodal cues capturing diverse facets of an event, and the need for integrating them in multimodal interfaces.

Our findings indicate important similarities and differences between the identified actively constructed cues and the traditional cues captured by lifelogging technologies. The latter have focused mostly on automatically captured external content. We have seen however that actively constructed cues, captured predominantly manually, emphasise internal content such as emotions and thoughts, in both nonverbal and verbal format. The latter tends to involve mostly tags or brief text captured at the time of the event, differing thus from the extensive text entry facilitated by common diary apps [20,31]. Our findings do not dispute the value of diary apps for long term capturing of life events, but argue for the complementary value of actively constructed cues in nonverbal modality capturing both external but particularly internal content. Our findings echo also the recent ones on the value of actively constructed cues as personalised flavours [23,24,25], or hand-made objects [56,61] self-defining memories, as emotionally charged, autobiographical memories.

5.1 Materializing both External and Internal Cues' Content

Previous work has critiqued lifelogging for being exclusively focused on retrieval and recollection, due to a technology-driven approach to data capture [35,64,71]. Our data provides a more nuanced understanding of the limitation of lifelogging technologies: their emphasis on *capturing readily available content*. This limits what lifelogging captures to the world *as it is here and now*, rather than how it is remembered, imagined or understood. Memories, however, can be triggered by both external and internal cues although the latter have been less addressed by lifelogging technologies. We found that some external cues invoking situational context could be *captured* through photos, or audio/video recordings of ambiance. In contrast, internal cues displaying emotional content *need to be constructed* through diaries and doodles. Active selection of objects cuing activities involve both photos capturing available objects, and doodles constructing the unavailable ones.

Elaborated Encoding

A third of the manually captured cues involved content construction. Despite the cost of their elaborate encoding, people enjoy its creative, playfulness quality, particularly while drawing doodles. Whether in textual, pictorial or aural form, such cues are the result of stronger engagement with the material they capture and the event to-be-remembered, offering several memory benefits: text-based cues communicate the reason for cueing the event, facilitating semantic meaning making, doodles support nonverbal emotional expression and processing, while aural cues allow for explanatory narratives [15]. Another significant outcome is that constructed cues are particularly preferred for reflection activities, supporting stronger recall of feelings. These outcomes extend generation effect [66] and elaborate encoding theory [3] to naturalistic settings.

While participants' generation of cues for recollection is not surprising, their efforts to use and appropriate tools – not purposefully designed to capture cues for reflection – is important. A significant outcome is that photos had limited value for reflection, which is better supported by cues capturing internal or unavailable content. The purposeful *construction* of such cues indicates that people value creating them and their support for reflection, suggesting the potential of lifelogging technologies for alternative memory functions.

Novel Tools for Constructing Nonverbal Emotional Cues
We have seen how verbal or nonverbal emotional content affects people's choices for distinct capturing tools. While diaries and audio/video recordings appear to support the capture of written or spoken emotional states, the extensive use of doodles for nonverbal emotional content indicates novel design opportunities. Here we should harness two critical doodle qualities emphasizing creative play and embodiment. Unlike diaries or aural recordings, doodles involve creative physical movement while drawing with fingers on the phone screen. This allows for a novel experience of constructing the cue, as each drawing act and its outcome is unique. Because of their more elaborate encoding, doodles support richer recall and reflection on feelings, particularly negative ones. To address the current limitation of lifelogging tools for constructing nonverbal emotional content, one can imagine novel technology classes capturing emotion-based cues – beyond fingers drawing on screens [56], but through arm movements or whole body moving or dancing in space, as detected by sensing technologies. Such cues will allow for increased embodied creative play adding rich experiential qualities to the encoding process.

Capturing and recalling negative emotional content could also have ethical implications, especially for people living with mental health conditions such as depression [53]. Particularly for depression, its specific memory impairments could not be easily addressed by cues captured by lifelogging technologies, and the call for novel interfaces to support generative rather than episodic retrieval has been made [52]. Given their more abstract quality, doodles could offer interesting opportunities for supporting generative retrieval, if sufficient ambiguity is injected in them. This is a promising direction for future research.

Better Support for Emotional Sense-Making
We found that verbal emotional content involves labelling discrete emotional states and causal thinking about emotions' determinants. The former is adequately supported by emoticons as reflected in their extensive use, while the latter enabled by the free text option in diary entries is less employed. While systems like Echo support reflection by prompting repeated evaluation of past emotional states [32], one can also imagine new technologies explicitly facilitating emotional sense-making through questions informed by reflection models [5], which can be also leveraged to support sense of self in old age [56,58,61].

Supporting New Perspectives on External Cues
Another important finding is the use of doodles to capture - besides emotions - additional types of unavailable content. Thus, unlike photos, doodles' representative drawings are constructed to capture absent physical objects, objects related to actions unfolding in time, or conceptual prototypical objects. The surprising use of doodles for the construction of these cues suggests novel design opportunities, which should exploit another two important doodle qualities: event summarization and shift of perspective. Both these qualities support not only more elaborate encoding, but represent also factors facilitating reflection [5,63]. To support reflection in this way, one can imagine novel automatic summarization techniques across photos or video content, or tools supporting verbal summarization in audio or video - which we have found that people struggle with – may be particularly useful. One can also imagine novel capturing techniques allowing fresh perspectives on the recorded content. While in doodles people often experiment with such perspectives, we have seen less such effort in photo capture, with the exception of an upside-down photo from P10. Techniques such as *macro close-up* or *camera restricta* can support such new perspectives, making the photo-based cues unique and open for reflection, while being easy to detect and retrieve in photo archives.

5.2 Beyond Metadata: Automatic Detection of Situational Cues

With respect to *where*- and *when-cues* capturing situational context, findings indicate that the ways in which people capture and recall places and times are not driven by metadata. People neither capture/tag nor recall memories triggered by such cues through canonical GPS logs or date/time stamps. Instead, they capture photos and use secondary objects within photos' content to display, infer or recall the spatio-temporal context. For example, secondary objects of spatial layout are mapped against events' locations and their scheduled occurrence.

Time is also captured in photos through daylight, and inferences about time of day from context, e.g., Christmas lights in a piazza. In addition, rather than relying on timestamps, people use event rhythms and temporal structure, or intentions for actions to navigate throughout the timeline of their episodic memories. These findings about the value of photo content to infer places and times may be explored through novel algorithms for automatic detection of such features in photos, which in turn can support better retrieval and recollection.

5.3 Supporting Integrated Multimodal Cues

Findings showed that cues are interdependent capturing and prompting recall of different facets of an event. Given the complementarity of external and internal cues, and their different preferred modalities, we suggest interfaces integrating them so that people can easily create most effective hybrid cues.

For instance, *where-cues* integrate multiple content categories capturing simultaneously Place, (secondary) Objects, (bystander) People, and Time. We interpret this through Fuchs' taxonomy [21] of body memory and his overarching multimodal category of situational memory storing the atmosphere of a situation [36]. Another significant outcome is that Feelings and People tend to be captured together. As interpersonal relationships and emotions are strongly interrelated [39], it is likely that *who-cues* in previous studies confounded People and Feelings, which may have inflated the frequency of *who-cues* [9,41,70]. We argue that decoupling them is important for advancing the understanding of cues.

In our interviews, cues were explored chronologically however, people expressed interest in novel interfaces integrating pictorial, textual and aural cues. We have also seen a match between cue content and modality, with different contents being preferentially captured through specific modalities or tools: emotions and sense-making through emoticons, diaries, abstract drawings, audio and video self- recordings; spatio-temporal situational context through photos and audio/video recordings of ambience, while activities through primary objects in photos or doodles. Interestingly, doodles offer the unique benefit of being open for creative appropriation [54] by capturing content across different pictorial modalities: textual, representational and textual.

One can envisage novel tools for content creation integrating multimodal input [23,24,25]; or capturing infrastructures supporting the match between the cue content and the best combination of tools supporting their capture. These could include novel interfaces integrating emotional and sense-making cues, with situational and activity cues such as the Echo system [32], or the integration of such systems with automatic capture of autonomic responses signalling events of personal relevance [59]. We can also imagine novel interfaces integrating most common audio-visual modalities with less explored gustatory modality. These could leverage technologies such as 3D printed food since previous findings have indicated their value for prompting recall with intense positive emotions, sensorial richness and feelings of being brought back in time [24,25].

6. LIMITATIONS AND FUTURE WORK

We acknowledge several limitations of our work. While our sample consisted of 12 participants, our unit of analysis was memory cues, i.e., 250 cues. Still, future work could benefit from focusing on large and more representative samples of participants aiming for age, and gender balanced samples. While beneficial, the act of actively creating the cues, could have been remembered more than the cues themselves. This poses an interesting tension. On the one hand, disambiguating this is not trivial, so future work may be needed, given the recall benefits identified by our findings. On the other hand, the act of creating the cue especially if involves novel or creative bodily movements, it will become intrinsically coupled with the cue, proving more memorable qualities. Future work is needed to explore this tension.

7. CONCLUSIONS

Our diary study explored how people actively capture and construct cues for meaningful events to-be-remembered. We advance theory on cueing episodic memories by finding evidence for the value of memory cues for reflection, and extending the generation effect to why-cues in naturalistic settings. Our findings led to design implications for cueing reflection through new lifelogging technologies supporting active construction of non-verbal emotional content and sense-making. We also suggest enabling new perspectives on externally available content, automatic detection of situational cues in photos, and integrating multimodal cues offering support for situational memory.

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