Can Less be More? Contrasting Limited, Unlimited, and Automatic Picture Capture for Augmenting Memory Recall

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Today's abundance[1] of cheap digital storage in the form of tiny memory cards put literally no bounds on the number of images one can capture with one's digital camera or smartphone during an event. However, prior work has shown that taking many pictures may actually make us remember less of a particular event. Does automated picture taking (lifelogging) help avoid this, yet still offer to capture meaningful pictures? In this work, we investigate the effect of capture modality (i.e., limited, unlimited, automatic, and no capture) on people's ability to recall a past event – with and without the support of the pictures captured through these modalities. Our results from a field experiment with 83 participants show that capturing fewer pictures does not necessarily lead to the capture of more relevant pictures. However, when controlling for number of pictures taken, our results show that having a limited number of pictures to capture may lead to pictures with increased memory value. At the same time, automated capture failed to produce pictures that would help remember the past experience better.

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General Terms: Lifelogging, Picture Capture, Picture Review, Human Memory Augmentation, Memory Recall

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1 INTRODUCTION

Modern digital storage and sensor miniaturization (in particular digital cameras) have created entirely new forms of capture practices, such as "lifelogging" [24]. Lifelogging entails the capturing of personal experiences in an automated and continuous fashion, utilizing hardware that includes not only (small) digital cameras but

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also positioning technology and physiological sensors. Lifelogging offers support for a range of activities. At the outset, it helps to simply record experiences (e.g., trips and sports) for sharing with others, later reminiscence, or for security reasons (e.g., a car dash cam). It also allows people to keep an overview of their progress and habits (e.g., smoking or eating), and serves as a personal reflection tool. Davies et al. envision the next step of such captured data to be the augmentation of human memory [6]. Instead of simply providing a convenient way to look up information once it is needed, Davies et al. suggest to use the data to prepare special *memory cues* that, when played back to the user in an ambient fashion, will reinforce recall and thus make it easier to remember the captured experience.

While lifelogging cameras can easily capture a comprehensive account of one's daily activities, the challenge is to select the few key moments to play back to the user as memory cues. This prompts 2 questions: (1) Are lifelogging cameras able to produce images that can serve as efficient memory cues? And (2) which images from a captured experience are best when used as memory cues? We approach these questions with a simple experiment, which investigates the effect of three different modes of picture capture – limited, unlimited, and automatic – on the ability of people to recall a past experience with and without the support of the captured pictures. Hence, we formed in total four conditions: Limited, in which participants could capture a limited number of pictures, unlimited, in which participants could capture as many pictures as they wished, automatic, in which participants relied on a lifelogging camera to capture pictures, and finally no tech, in which participants took no pictures at all. All participants, in all three conditions that entailed picture capture were instructed to in the similar manner, so that they use any available picture capture means at their disposal for maximizing their recall capabilities about the experience at later stage. By contrasting manual with automated picture taking, we attempt to understand *if* (and *how*) conscious image framing results in images that are better able to act as memory cues later. By contrasting limited and unlimited picture capture, we try to understand *if* fewer images will lead to better memory cues. We ran a "campus tour" with 83 participants, grouped into different capture conditions, and asked them later to recall their experience with and without the use of pictures they had captured. Participants in the "automatic" condition were equipped with a 1st generation Narrative Clip [31] – they were able to focus on the tour and were able to draw on literally hundreds of images to remember the tour later. Those in the "unlimited" group were allowed to use the standard camera app in an Android phone to take as many pictures as they wanted – this should produce high quality images but may be affected by the "photo-taking impairment effect". The "photo-taking impairment effect" describes the detrimental impact that manual picture capture may entail on the formation of strong memories [12]. For limiting the number of pictures one can capture, we used a mobile app called "*My Good Old Kodak*" (MGOK) [21], which artificially limits the number of pictures one can take with a smartphone to 24 – we expected this to balance image quality with photo-taking impairment.

2 BACKGROUND

People capture content (e.g., video, pictures etc.) in an effort to amplify and prolong positive emotional experiences. Lifelogging has been long viewed as a promising approach for capturing content that would later assist reminiscence, primarily for its "always-on" capturing nature [25]. As such, lifelogging is the practice of continuous capture of data streams that characterize a life experience. A lifelogging system typically stores captured data in a way that people can subsequently review past experiences and episodes of their everyday lives – for reminiscing, self-reflection, planning future actions, or to alter or sustain behaviors and habits [11]. Lifelogging as an idea was first introduced by the Vannevar Busch in 1945, when he proposed the "Memex" [25] concept, a device that one would use for storing individually one's books, records, and communications with the purpose of consulting it later for enlarging and supplementing one's memory. Gordon Bell's "MyLifeBits" lifelogging system, started in 2001, is perhaps the closest attempt to materialize the concept of a

Memex, in that it attempted to not only store scanned version of printed documents, photos, or home movies, but also automatically capture all of his digital communication, e.g., phone calls, IM messages, and of course e-mails [10]. With the advent of mobile and wearable technology, in particular the sensor-enabled modern smartphone, lifelogging became increasingly popular. Lifelogging is intended to be ubiquitous, recording continuously and passively a wide range of aspects about one's daily life through some sort of lifelogging device. Lifelogging devices can be wearable cameras (e.g., the Narrative Clip[2]), biophysical monitoring devices (e.g., Empatica[3] E4 wristband), fitness trackers (e.g., Fitbit[4]), a modern smartphone, web-enabled cameras, and other sorts of devices that capture aspects and activities of our daily lives. Captured data from different sources are then typically processed, synced, and stored, to form personal digital multimedia records ("lifelogs") [7, 14], with video and/or pictures, typically comprising the "core" of a lifelog.

Pictures in particular can be viewed to elicit feelings and emotions, but they can also remind one of past experiences (that a personal event took place) and serve as a cue to elicit related memories associated with that event (so-called *episodic memory*) [3,7]. Episodic memory stores contextual information regarding *who*, *what*, *where* and *when,* and has a fundamentally visual nature [29]. Pictures hold an excellent potential in triggering episodic memories due to their so-called "*configural nature*" and their ability to represent entities in relation to each other, thus maximizing the information they contain [5]. A prevalent example of an application based on episodic memory theory is *SenseCam*, a small wearable camera that hangs around the neck and captures pictures automatically in the course of a day [13]. *SenseCam* pictures would later be used for assisting one's recollections, triggering episodic and autobiographical memories. Lee and Dey used *SenseCam* pictures for investigating which elements in a picture can improve episodic memory recall and discovered that co-presence of people in images is often associated with more vivid recollections [16]. However, while the added value of lifelogging cameras, such as SenseCam, has been showcased in clinical studies (e.g., with patients suffering from amnesia [13], Alzheimer's disease, and episodic memory impairement [15]), their potential in augmenting episodic memory recall in everyday settings has received little attention. The *Narrative Clip 2* [31] could be considered the most recent and most compact successor of *SenseCam*, and is intended for capturing everyday life experiences. The Clip captures pictures automatically every 30 seconds, while also supporting video capture GPS tracking and Wi-Fi/Bluetooth connectivity for synchronizing content with mobile and desktop devices. The Narrative Clip can also explicitly capture a picture by "double tapping" on it. For the purposes of this study, we have used the predecessor of the current version, the *Clip 1,* and we did not inform our participants about the explicit picture capture feature.

However, lifelogging and automatic capture come with significant drawbacks. The "always-on" capture fashion of lifelogging entails the capture of an enormous volume of (visual) information that is often irrelevant to the experience one strives to record and subsequently remember, thus leading experts to advocate for the need of "*selectivity, not total capture*" in lifelogging [25]. This selectivity is often considered as a necessity in designing successful and usable lifelogging systems [30]. In fact, a sizeable body of research is dedicated to filtering content in lifelogging, either *pre* or *post* capture, for limiting the content one has to review in order to remember. As a post capture example, Ehlen et al. propose the utilization of machine learning techniques for creating a meeting summarization tool that performs natural language processing on participants' recorded utterances and subsequent topic analysis on the transcripts to summarize topics discussed [8]. Several pre capture examples propose event driven sampling for selecting which moments are significant for assisting one's later recall and elicit User Experience (UX) quality levels. *EmoSnaps* is a mobile app that captures unobtrusively one's facial expressions based on a set of predefined actions on a mobile

[2] See http://getnarrative.com
[3] See https://www.empatica.com/
[4] See https://www.fitbit.com/home

device (e.g., slide in) and uses them for the later recall of one's momentary emotions [19]. Similarly, *eMotion* is a mobile app prototype that captures unobtrusively short clips of driver's facial expressions along with road pictures during driving and additional contextual information under certain criteria (e.g., location and speed) and plays them back later to the driver for safely assessing driver's UX off-road [20]. Other lifelogging approaches introduce the use of biophysical sensors hosted in a wristband for inferring a user's arousal levels and drive picture capture (pre capture) [22] or picture selection (post capture) [23]. In fact, Sas et al. found that pictures captured during higher GSR levels were able to trigger significantly richer recollections when reviewed, than pictures captured during lower GSR levels [23].

A different approach, which puts the selection control back into the hands of the user, is our "*My Good Old Kodak*" (MGOK) mobile app [21]. The MGOK app (see Fig. 1) attempts to reintroduce the classic paradigm of the old film cameras by artificially restricting the number of the pictures one can take, and at the same time hiding them from the device's photo gallery. The authors hypothesize that an imposed capture limitation would also result in taking pictures of higher importance, which would later support recall significantly better than ordinary pictures do. While Henkel [12] showed that the mere act of picture taking can be disruptive for the formation of new memories, and thus reduce the quality of recall (the so-called "photo-taking impairment effect"), Henkel's study did not have any limitations in the number of pictures taken. Also, recent work by Nightingale et al. [26] was unable to reproduce Henkel's findings.

In our work, we thus wanted to contrast three distinct types of capture modality – *limited*, *unlimited* and *automatic* – in terms of their impact on human memory (i.e., through the act of capture) as well as their suitability for generating memory cues. Our contribution is hence threefold: First, we measurably estimate the memory loss that a capture modality imposes on those that take pictures during an event (i.e., quantify the photo-taking impairment effect across further capture modalities) [12]. Second, we measurably estimate the added value (i.e., memory gain) of pictures originating from all three capture types on one's ability to recall an experience at a later stage. Last but not least, we attempt to differentiate between two different explanations for the photo-taking impairment effect: (a) due to the distraction caused by manual picture taking or (b) due to disruption at encoding as a result of having external memory support [27, 28]. Among others, we were also able to obtain the level of engagement with the campus experience and perceived quality of captured pictures as influenced by the use of different capture modalities.

We expect that the "photo-taking impairment effect" will manifest for participants that captured pictures manually when they are asked to recall any details about the experience (i.e., campus tour) at a later stage, without the support of the pictures they took. However, when these participants review their manually captured pictures, they will be able to recall significantly more details than those that captured pictures automatically with a lifelogging camera. Particularly, we believe that participants that captured a limited number of pictures throughout the campus tour experience (i.e., limited condition) they will exhibit a higher memory gain when reviewing these pictures, as an effect of resource scarcity that perhaps forced them to capture more meaningful pictures. Similarly, we expect pictures that were captured in the "limited" condition will be rated as more meaningful and of better quality.

3 STUDY

For examining the aforementioned picture capture effects, we organized a campus tour event, offered to undergraduate students at the University of Essex's Colchester Campus in the UK. A campus tour offers a fun experience for participants involved, but also provides for a structured experience, allowing us to investigate the effects of different picture capture strategies on different participant groups in a relatively controlled setting. Following a between-subjects study design, we split registered participants into four distinct groups, of approximately equal size:

- **Group A - No tech**: This group was not equipped with any capture technology and was intended as the control group. Participants simply attended the campus tour by following the researcher while listening to her for each place they were visiting.
- **Group B - Unlimited** (smartphone with native camera app): This group was equipped with smartphones that had a native camera app installed. Participants could take as many pictures as they wished during the campus tour.
- **Group C - Limited** (smartphone with MGOK app): This group was also equipped with smartphones but the native camera app was replaced with the MGOK app, which restricts the number of pictures each participant could take to 24. Similar to Group B, participants of Group C could capture a picture with the MGOK any time they wished.
- **Group D - Automatic** (Narrative Clip): Lastly, a group of participants was equipped with the Narrative Clip, a lightweight wearable camera that one can clip onto one's clothes (typically at or below neck height) for capturing pictures automatically every 30 seconds.

We formed the following hypotheses:

H1 Participant groups that captured pictures manually (Group B - unlimited and C - limited) will exhibit lower memory scores at a later unassisted recall of the campus tour experience than groups that capture pictures automatically (Group D - automatic) or did not capture pictures at all (Group A – no tech), due to the "photo-taking impairment effect" [12]. For the same reason, we also expect lower engagement with the tour in Group B and C.

H2 Pictures captured with the smartphone's native camera app (Group B) will be rated as more difficult to review due to their increased quantity. In fact, this hypothesis is in line with prior work that stresses the need for "selectivity, not total capture" in lifelogging, in that carefully selected content may be more valuable for one's memory recall than large volumes of (often indifferent and highly similar) content [25]. However, we expect that, since they are manually captured, these pictures still hold a considerable potential to improve participants' ability to recall the campus tour experience, displaying increased memory value and reported as more memory supportive than pictures taken with the Narrative Clip (Group D).

H3 Pictures captured with the MGOK app (Group C) will hold higher "memory gain" as compared to pictures captured in all other conditions, both in terms of memory scores after picture review and as rated by the participants. The imposed picture capture limitation should lead to a more selective capture behavior and hence increased (perceived) value [17].

H4 Pictures captured with the Narrative Clip (Group D) will have a much lower perceived quality than manually captured pictures (Group B and C), due to its automated operation [4]. We also expect that participants of Group D will rate their pictures as less meaningful and will indicate lower feeling of ownership and engagement when reviewing them.

3.1 Participants

In total, we recruited 83 participants (55 were female) with an average age of 25 years (M = 25.301, SD = 8.849). All participants were Essex University Psychology undergraduates, with varying levels of familiarity with the campus' whereabouts and its past. Participants were compensated with £18 for their participation (except for first year psychology students who were given 3 course credits for one of their modules). Participants were recruited through the Psychology department's recruitment website for participating into a memory study that includes a campus tour.

3.2 Procedure

Participants were first informed about the study and its purpose, and then asked to sign an informed consent form. We randomly assigned each of the 83 participants to one of the four groups described above, in order to achieve a balanced distribution (Group A: 22; Group B: 20; Group C: 21; Group D: 20). All participants were told that they would participate in a memory experiment about the University Campus, in which a researcher would take them on a roughly 60-minutes tour of the campus, visiting a total of 10 distinct locations. Participants in groups B and C (limited and unlimited capture) were instructed to use a provided capture device (an Android smartphone) to take pictures that would help them later to better remember the places they visited. However, no examples on how to capture the tour were given (e.g., when and how to capture a picture). Participants in group D were given a Narrative Clip (see Fig. 2) and were asked to pin this to their shirts or jackets during the tour. We explained participants how the Clip would automatically take a picture every 30 seconds, and that they could later use these pictures to aid their memory. Note that while the Clip also supports manual picture taking (by quickly double tapping it), we did not tell participants about this feature, as the goal was to investigate the Clip's automated operation only. None of the participants in group D had seen or used a Narrative Clip before, and hence no one used this feature during their tour. No other picture capturing equipment was permitted during the tour for all conditions – neither digital cameras nor personal smartphones (participants had to leave these in the researcher's office at the beginning of the tour). Participants in group A had thus no capture device at all with them during the tour.

Each tour group had between 2-4 persons, of which all were undergoing the same condition, i.e., all participants in a tour were using the same capture modality throughout their campus visit (a between-groups design). At each of the 10 distinct locations, participants where shown 6 specific items (identical items for all groups), and were told an interesting "fact" about each specific item. For example, at the library (a distinct location), participants were shown a printer, a sculpture, a painting, the floor plan, lifts, and Japanese dolls, and for each they were told a fact; e.g., for the dolls the fact was "*These were donated by a Japanese diplomat*". The fact that our campus tour did not only focus on the geographical setting and its physical artifacts, but also on more or less arcane info at various landmarks, ensures that even students more familiar with the campus would still have a memorization task.

After the campus tour had ended, participants were invited individually to the lab, where they were given a 10-minutes time to relax during which they could use their personal smartphones to access the internet or chat online. During that time, we collected any material that was captured either with the smartphones given to the participants (i.e., both the native camera app and the MGOK app) or with the Narrative Clips. Immediately afterwards, participants were asked to perform a *memory test* of the campus tour experience.[5] Participants were presented with all the names of the distinct locations they had visited during the campus tour in a random order and were asked to write down for each distinct location as many specific item names as they could remember. For each distinct location, participants had 30 seconds before moving to the next one. After participants were finished, we collected their responses and calculated later their individual memory scores based on how many specific items they could accurately recall.

A week later, participants returned to the lab to perform a "delayed recall task". Participants were instructed to write down their experience of the campus tour in 10 different episodes, each one corresponding to the 10 distinct locations they had visited a week before. Participants were asked to describe those locations

[5] Note that for the purpose of a second experiment, completely unrelated to the purpose of this article, *half* the participants in each experimental group received retrieval practice on *half* the specific items from *half* the locations before they started the memory test. Our data reported in this article thus excludes the results on these (five) locations for which this half of our participants received additional retrieval practice.

Fig. 1. User Interface of "My Good Old Kodak" (MGOK) app, the Camera app replacement installed for participants in Group C (Limited). The screenshot shows the configuration we used for the campus tour, with a maximum number of 24 pictures.

with as many details and events they could recall as possible. For this task, we allowed a maximum duration of 10 minutes in total. Then, participants that belonged to groups that captured images during the campus tour (i.e., Groups B, C or D) were given a maximum of ten minutes to review the content they previously captured, either with the native camera app, the MGOK app (Fig. 1), or automatically using a Narrative Clip (Fig. 2) (depending on which group they were in), on a computer in the room. We allowed a maximum time of 10 minutes for the content review session, although most participants found 10 minutes more than sufficient. We also recorded their individual content review time. For group D, we purposefully did not let participants use the Narrative app – the bundled mobile software that comes with the Narrative Clip, offering an automatically curated selection of a person’s daily pictures (called “moments”), similar to services such as Google Photos. Instead, they simply received all pictures captured during the tour (typically between 100 to 110) in a file folder on the computer, similar to Groups B and C. While this entailed more effort than simply reviewing the curated selection made by a tool like the Narrative app, participants were still able to look through the pictures in a few minutes. Also, we did not want to test the quality of the Narrative app in selecting important pictures, in particular since the Narrative app selection might filter out certain pictures (e.g., blurry ones), yet these may still hold information that could trigger episodic memory recall. After the review (which only took place for participants from Groups B, C and D), participants were asked to perform again the serial recall task. Participants who did *not* capture pictures (Group A) were instead given an 8-minutes interval with no specific instructions, after which they then simply repeated the serial recall task process. Same as before, participants were asked to cluster their memories about the campus tour in 10 episodes corresponding to each of the 10 distinct locations they had visited a week earlier. We allowed a maximum duration of 10 minutes for the second serial recall task.

Upon ending, participants whose groups entailed picture capture answered a series of questions in a 5-point Likert scale, ranging from 1 (“not at all”) to 5 (“very much”), inquiring into the perceived ability to manage the captured images, the quality of the images, their feeling of ownership over the images, how meaningful they found the captured pictures, as well as their subjective engagement during the review of their pictures. All participants (also those from Group A) were asked to report on how engaged they felt during the campus tour, using the same 5-point Likert scale. We also collected qualitative insights by asking participants to describe their feelings about the campus tour and (for Groups B, C, and D) whether the provided capture device was helpful in engaging and/or remembering about their campus tour experience.

3.3 Apparatus

As outlined in the study description, the only group of participants that relied solely on their memory for recalling the campus tour experience was Group A, thus acting as a control group. Participants in groups B and C were each given a Samsung Galaxy S3 Mini smartphone running Android OS version 4.2.2 with an 8 Megapixel camera resolution. While participants in Group B were asked to simply use the native Samsung camera app, participants in Group C were given smartphones in which we had replaced the native camera app with our MGOK app [21]. The MGOK app offers a maximum of 24 pictures and informs the user about the remaining shots they can take. It also requires a long-press on the shutter button in order to first focus and then capture a picture. Captured pictures are deliberately hidden from the device's photo gallery. The MGOK app (see Fig. 1) thus tries to approximate as much as possible the traditional film cameras that required one to focus before taking a picture and develop the film before one could see the result.

Fig. 2. Narrative Clip 1, used for automated capture.

Finally, Group D used the Narrative Clip 1 (see Fig. 2), which we clipped to participant's clothes (typically on the neck of a shirt, or lapel of a coat) for capturing pictures automatically every 30 seconds. The Narrative Clip 1 is equipped with a 5-megapixel camera sensor and has a battery life of approximately 2 days. While the Narrative Clip also supports explicit/manual capture by double tapping on it, we intentionally did not inform participants about this feature. As the Clip tags such manual captures in the captured picture's metadata, we were able to verify that none of our participants actually used this feature.

3.4 Measures

For examining our hypotheses, we employed a series of quantitative and qualitative measures, both of objective and subjective fashion. First, we measured each participant's ability to accurately recall the campus tour experience in 3 distinct stages, resulting in 3 memory scores: a) right after the campus tour ($score_{AfterTour}$), b) a week after the campus tour ($score_{AfterAWeek}$), and c) a week after the tour and after reviewing their content ($score_{AfterReview}$). Memory scores measured the percentage of specific items recalled from those shown at each distinct location in the campus tour, ranging from 0 (no recall) to 100 (absolute recall) and were obtained using the *category-cued recall* method [1,9], with "spatial location" as the category and "items in that location" as the exemplars. This enabled us to perform comparisons between different participant groups/conditions and at different stages, and even compute memory gain and loss rates in % between recall stages. Also, based on memory scores recorded at different stages, we were able to quantify the *memory loss* that participants experienced a week after the campus tour and the *memory gain* after the picture review. As *memory loss* we define the difference in % between memory scores recorded right after the campus tour ($score_{AfterTour}$) and memory scores a week after the campus tour was completed ($score_{AfterAWeek}$). We consider *memory loss* an indicator of memory deterioration due to the manual capture of pictures (i.e., "photo-taking impairment" effect [12]) and/or due to relying on pictures captured as an external memory prosthesis [27,28]. As *memory gain* we define the difference in % between memory scores recorded a week after the campus tour ($score_{AfterTour}$) and memory scores after picture review ($score_{AfterReview}$). We consider *memory gain* an indicator of the potential that pictures hold in assisting one to recall a past experience. Additional measures were

Table 1. Overview of all measures used in the study and their descriptive statistics (i.e., average and standard deviation in brackets).

Measures (scale) / Condition	**Group A**	**Group B**	**Group C**	**Group D**
$score_{AfterTour}$ (%)	67.341 (15.077)	59.555 (12.007)	59.082 (15.415)	63.648 (13.88)
$score_{AfterAWeek}$ (%)	57.811 (17.552)	47.5 (16.226)	42.698 (17.043)	50.907 (18.219)
$score_{AfterReview}$ (%)	63.417 (19.481)	65.018 (21.184)	55.801 (21.004)	54.259 (21.526)
number of pictures	0 (0)	76.55 (25.787)	22.714 (2.512)	105 (12.579)
review time (mm:ss)	00:00 (00:00)	04:17 (02:29)	02:07 (01:24)	02:35 (00:46)
memory loss (%)	9.528 (12.166)	12.055 (13.79)	16.384 (16.023)	12.74 (12.39)
memory gain (%)	5.606 (8.412)	17.518 (18.686)	13.102 (12.998)	3.351 (10.398)
S1 "image quantity" (1 - 5)	N/A	2.6 (1.095)	1.904 (.83)	2.55 (1.316)
S2 "memory aid" (1 - 5)	N/A	4.3 (.978)	4.19 (.928)	3.5 (1.147)
S3 "ownership" (1 - 5)	N/A	4.2 (1.105)	3.19 (1.749)	2.65 (1.496)
S4 "image quality" (1 - 5)	N/A	3.25 (1.292)	3.571 (1.164)	2.85 (1.225)
S5 "semantic value" (1 - 5)	N/A	3.85 (.933)	3.238 (1.22)	2.3 (.801)
S6 "review engagement" (1 - 5)	N/A	3.6 (.994)	3.095 (1.135)	3.4 (.94)
S7 "tour engagement" (1 - 5)	4.09 (.683)	4.15 (.745)	3.809 (.813)	4.05 (.686)

"number of pictures captured" and "picture review time" per condition. Next, for comparably inquiring into the participants' views over the content they captured and then reviewed, we used 7 subjective measures in a 5-point Likert scale fashion. In particular, we asked participants to indicate how much they agree from 1 ("not at all") to 5 ("very much") in a 5-point Likert scale with the following 7 statements:

S1. *Image quantity*: "I felt the pictures were too many to manage."
S2. *Memory aid*: "I think the pictures helped me remember of the campus tour."
S3. *Ownership*: "I feel like the pictures belonged to me /were mine."
S4. *Image quality*: "I think the pictures were of good quality."
S5. *Semantic value*: "I think the pictures captured meaningful content."
S6. *Review engagement*: "I think reviewing my pictures was an engaging (i.e., exciting) task."
S7. *Tour engagement*: "I think the campus tour was an engaging experience."

For an overview of all measures used in the study along with their descriptive statistics, see Table 1. Finally, we also collected participants' comments about the campus tour, the picture capture and picture review experiences.

4 RESULTS

In this section, we present our analyses' results grouped around our previously stated hypotheses. As mentioned in section "3.2 Procedure" above, for the purpose of an experiment unrelated to the aims of this article, half of our participants received retrieval training for items from half (i.e., five) of the visited locations. Our results thus report data from our 83 participants as follows: 43 participants' memory performance from 10 unpracticed locations, together with 40 participants' memory performance from the 5 unpracticed locations that were unaffected by this otherwise unrelated memory intervention.

4.1 Photo-taking Impairment Effect (H1)

First, we investigated the effect of picture capture on memory scores across all four groups (i.e., conditions). Particularly, we examined the effect of condition type on participants' memory scores at three points in time: right after the campus tour was completed, one week later before reviewing the pictures, and one week later after reviewing the pictures taken during the tour. In order to differentiate between two different explanations of the photo-taking impairment [12] effect, we need to compare two different sets of scores: if the effect is due to the distraction caused by manual picture capture, we expect the scores of Groups A and D to be higher than in groups B and C. If the effect is due to disruption at encoding because participants rely on having external memory support, we should observe Group A's score to be significantly higher than any of the other three groups.

Levene's tests of homogeneity and Shapiro-Wilk tests of normality confirmed the assumptions of homogeneity of variance and normality, respectively, of the dependent variables $score_{AfterTour}$, $score_{AfterAWeek}$, and $score_{AfterReview}$, for the independent variable condition type. A separate one-way analysis of variance was performed for each set of scores at the three different intervals ($score_{AfterTour}$, $score_{AfterAWeek}$, and $score_{AfterReview}$) to compare the effects of condition type (the independent variable). The analyses displayed no significant main effect for $score_{AfterTour}$ ($F(3,79) = 1.588$, $p = .199$, $\eta_p^2 = 057$), a significant main effect for $score_{AfterAWeek}$ ($F(3,79) = 2.904$, $p < .05$, $\eta_p^2 = .099$) and no significant main effect on $score_{AfterReview}$ ($F(3,79) = 1.374$, $p = .257$, $\eta_p^2 = .05$). This indicates that participants' memory scores right after the campus tour and a week later after picture review did not differ significantly across all conditions (see Fig. 3). However, participants' memory scores a week after the campus tour but before picture review, displayed a significant variation across different conditions. In fact, post hoc tests using the Bonferroni correction revealed that participants in Group A (No tech: M = 57.811 %, SD = 17.552 %) were able to recall significantly more about the campus tour a week after it was completed, than participants in Group C (Limited: M = 42.698 %, SD = 17.043 %, $p < .05$) did (see Fig. 3). However, no significant difference was found between Group A and participants in Groups B (Unlimited: M = 47.5 %, SD = 16.226 %, $p = .342$) and D (Automatic: M = 50.907 %, SD = 18.219 %, p = 1), respectively. This seems to indicate that the photo-taking impairment effect is not simply due to having an external memory support (i.e., disruption at encoding). However, independent samples t-tests revealed significant differences in $score_{AfterTour}$ ($t(81) = - 2.027$, $p < .05$) and $score_{AfterAWeek}$ ($t(81) = - 2.493$, $p < .05$) between participants who captured pictures manually (Group B and C together) ($score_{AfterTour}$: M = 59.313, SD = 13.687 | $score_{AfterAWeek}$: M = 45.04, SD = 16.619) and those who did not (Group A and D together) ($score_{AfterTour}$: M = 65.582, SD = 14.463 | $score_{AfterAWeek}$: M = 54.523, SD = 17.994), indicating the presence of the "photo-taking impairment" effect due to the distraction caused by manual picture capture.

Next, we investigated *if* a possible presence of the "photo-taking impairment" effect would manifest as a lower self reported tour engagement (S7) for participants who actively captured pictures during the tour (H1). In overall, Shapiro-Wilk tests of normality did not confirm the assumption of normality for the independent variable condition type for statements S1: "*Image quantity*" (B: $p = .033$, C: $p = .002$, D: $p = .032$), S2: "*Memory aid*" (B: $p = .000$, C: $p = .000$, D: $p = .007$), S3: "*Ownership*" (B: $p = .000$, C: $p = .000$, D: $p = .008$), S4: "*Image quality*" (B: $p = .028$, C: $p = .038$, D: $p = .128$), S5: "*Semantic value*" (B: $p = .01$, C: $p = .009$, D: $p = .012$), S6: "*Review engagement*" (B: $p = .005$, C: $p = .112$, D: $p = .018$) and S7: "*Tour engagement*" (B: $p = .001$, C: $p = .009$, D: $p = .001$). Non parametric Levene's tests of homogeneity did not confirm the assumption of homogeneity of variance for the independent variable condition type for statements S2: "*Memory aid*" ($p = .031$), S3: "*Ownership*" ($p = .013$) and S5: "*Semantic value*" ($p = .000$). Hence, for these statements, we proceeded with non parametric Moods Median Tests. For the remaining statements (S1: "*Image quantity*", S4: "*Image quality*", S6: "*Review engagement*" and S7: "*Tour engagement*"), non parametric Levene's tests of homogeneity confirmed the assumption of variance for the independent variable condition type, hence we proceeded with a series of

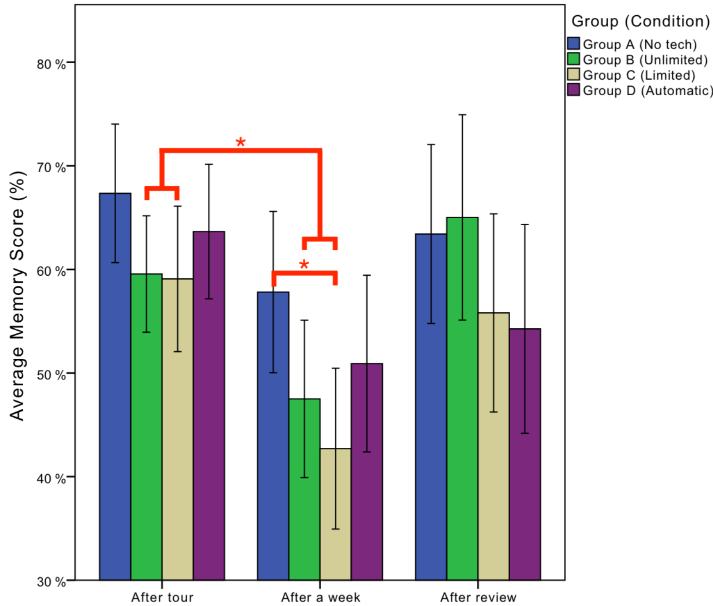

Fig. 3. Participants' average memory scores (%) per condition: right after the campus tour, a week after and after picture review. Group A remembered significantly more than Group C a week after the campus tour. Statistically significant differences are marked with an asterisk for a value of $p < .05$.

non parametric Kruskal-Wallis tests. As such, for statement S7: "*Tour engagement*", a nonparametric Kruskal-Wallis with participants' tour engagement reported levels as dependent variable and condition type as independent variable displayed no significant effect for condition type (S7: $\chi^2(2) = 1.93$, $p = .381$, $\eta_p^2 = .032$). This again does not confirm H1, which assumes that participants who actively took pictures during the campus tour (Groups B/C) would report less engagement than those who did not (Groups A/D). A visual oveview of the reported agreement with all statements can be found in Fig. 4.

In general, participants perceived the campus tour as fun, engaging and at times educational experience.

> "[P43] *The campus tour was engaging I felt like a tourist...* [P9] *It is like trivial pursuit but quite interesting to learn some less known fact about the university.* [P2] *It was really exciting to know more about the campus.* [P10] *It was very nice to learn the facts about various things around campus.* [P30] *It was nice to go around places I knew and learn information about them as well as viewing sites I never did before... it made me feel more engaged with the campus."*

Some participants got tired and distracted towards the end and felt that they were visiting places in an irrational order:

> "[P79] *The campus tour was educative but tiring.* [P1] *I started getting distracted by the end of it and paying less attention to the details...* [P47] *It starts to get a little boring when we visited a couple of places already.* [P22] *Campus tour was interesting, but the places were not arranged in accordance to distance to each other (it was more like a zigzag).* [P43] *The order of the locations was confusing because I normally do not visit these venues in that order."*

Assuming participants' tiredness would influence their recall scores and be expressed in lower campus engagement (S7) levels, we computed Spearman rank-order correlation coefficients to assess the relationship

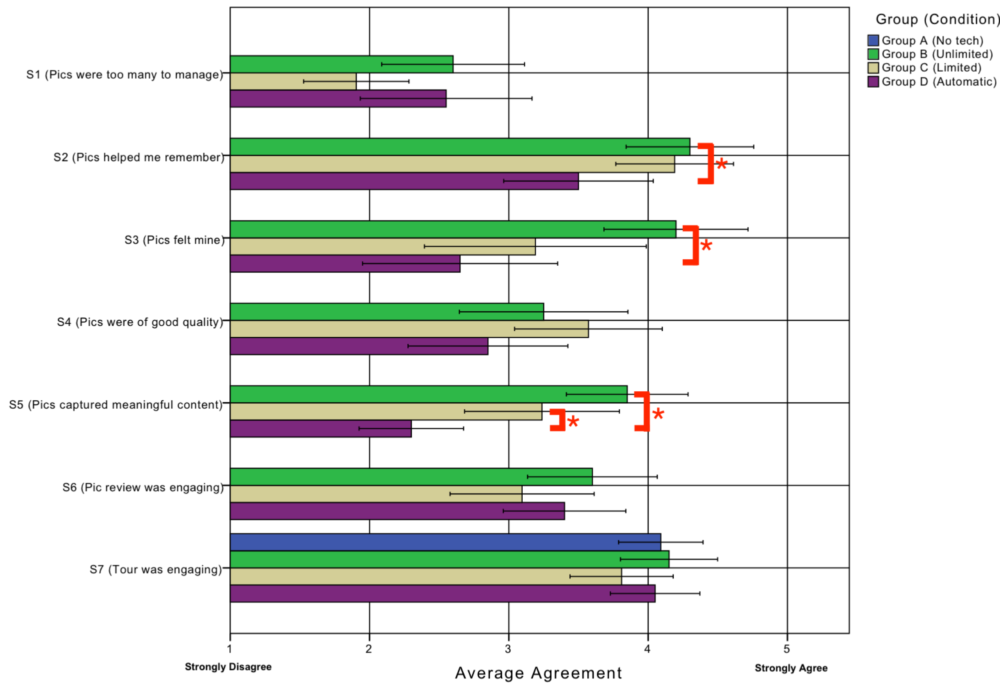

Fig. 4. Average agreement with all statements (S1 – S7) in 1 ("Strongly Disagree") to 5 ("Strongly Agree") scale for the respective study conditions. We purposefully present averages (and not medians) for unveiling even the smaller differences across all conditions. Statistically significant differences are marked with an asterisk for a value of $p < .05$.

between S7 and all memory scores. However, no significant correlation was found between S7 and all memory scores ($score_{AfterTour}$: $r_s = .018$, $p = .874$, $n = 83$ | $score_{AfterAWeek}$: $r_s = -.086$, $p = .441$, $n = 83$ | $score_{AfterReview}$: $r_s = -.049$, $p = .66$, $n = 83$).

4.2 Unlimited Manual Capture Effect (H2)

Next, we calculated the difference between memory scores achieved right after the campus tour was completed (i.e., $score_{AfterTour}$) and memory scores a week after the campus tour was completed (i.e., $score_{AfterAWeek}$), as a measure of memory deterioration and we encoded it in a new variable (i.e., memory loss in %). A one-way analysis of variance with participants' memory loss scores as a dependent variable, and condition type as an independent variable, displayed no significant main effect for condition type ($F(3,79) = .917$, $p = .437$, $\eta_p^2 = .034$). This indicates that participants' memory loss rate over a week did not vary significantly across different picture capture modalities (see Fig. 5). Note that even though there was no significant difference in the memory loss rate, the overall memory scores (see Fig. 3) still differed significantly (H1).

Similarly, for quantifying the added value of pictures in participants' ability to recall about the campus tour event that had taken place a week before the recall sessions, we created a memory gain variable (%). Memory gain is the difference between participants' memory scores before (i.e., $score_{AfterAWeek}$) and after (i.e., $score_{AfterReview}$) picture review, a week after the campus tour had been completed. A one-way analysis of

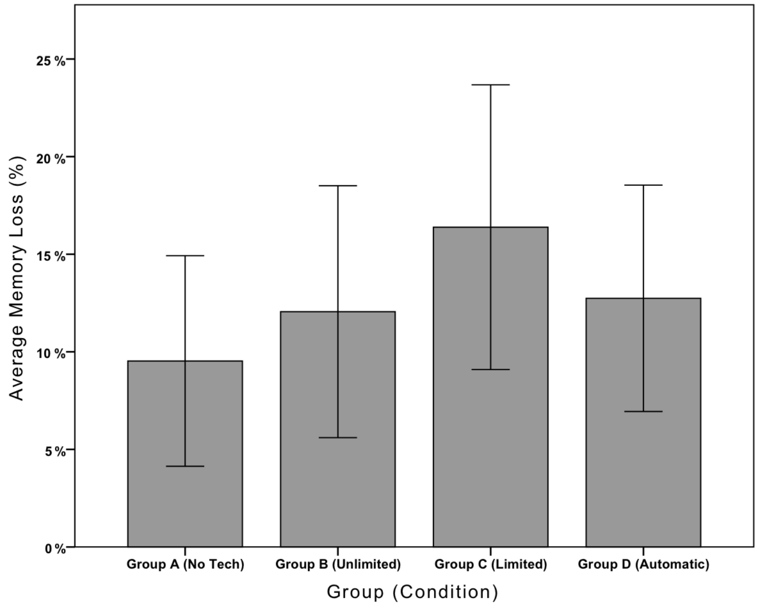

Fig. 5. Average memory loss (%) per group/condition a week after the campus tour, without the support of captured pictures.

variance with participants' memory gain rate as a dependent variable and condition type as an independent variable, displayed a significant main effect for condition type ($F(3,79) = 5.127$, $p < .05$, $\eta_p^2 = .163$).

Post hoc tests using the Bonferroni correction revealed a significant difference in the memory gain rates of participants who reviewed pictures captured with smartphones (Unlimited: $M = 17.518$ %, SD = 18.686 %), as opposed to participants who reviewed pictures captured automatically with the Narrative Clip (Automatic: $M = 3.351$ %, SD = 10.398 %, $p < .05$) and participants who did not review pictures at all (No tech: $M = 5.606$ %, SD = 8.412 %, $p < .05$). In fact, a paired samples t-test with $\text{score}_{\text{AfterAWeek}}$ ($M = 50.907$ %, SD = 18.219 %) and $\text{score}_{\text{AfterReview}}$ ($M = 54.259$ %, SD = 21.526 %) for participants who used the Narrative Clip (i.e., Group D) revealed no significant memory improvement after the picture review ($t(19) = -1.442$, $p = .166$). This indicates that pictures captured with smartphones potentially hold a significantly higher memory gain than pictures taken with the Narrative Clip, or no pictures taken at all (see Fig. 6). This finding is in line with hypothesis (H2) in that manually captured pictures hold a higher potential to increase a participant's ability to recall an experience.

Kruskal-Wallis tests with participants' reported difficulty to review pictures (S1: "*Image quantity*") as dependent variable and condition type as independent, displayed no significant main effect for condition type (S1: $\chi^2(2) = 4.872$, $p = .088$, $\eta_p^2 = .082$) in contrast to an expected review difficulty imposed by a large number of pictures to review in the Group B (unlimited condition). However, a non parametric Moods Median Test with S2: "*Memory aid*" as dependent variable and condition type as independent variable, displayed a significant main effect for condition type ($\chi^2(2) = 7.174$, $p < .05$). Post hoc pairwise comparisons using Pearson's chi square tests revealed a significant difference in the medians between condition B (*Mdn* = 5, and D (*Mdn* = 4) ($\chi^2(1) = 7.03$, $p < .05$, $V = .419$) but no significant difference between condition C (*Mdn* = 4) and B (*Mdn* = 5) ($\chi^2(1) = .605$, $p = .437$, $V = .121$) or condition C (*Mdn* = 4) and D (*Mdn* = 4) ($\chi^2(1) = 3.84$, $p = .05$, $V = .306$). This indicates that participants who reviewed pictures that they captured with smartphones (Group B) reported systematically higher *memory aid* than participants who reviewed pictures that they captured with

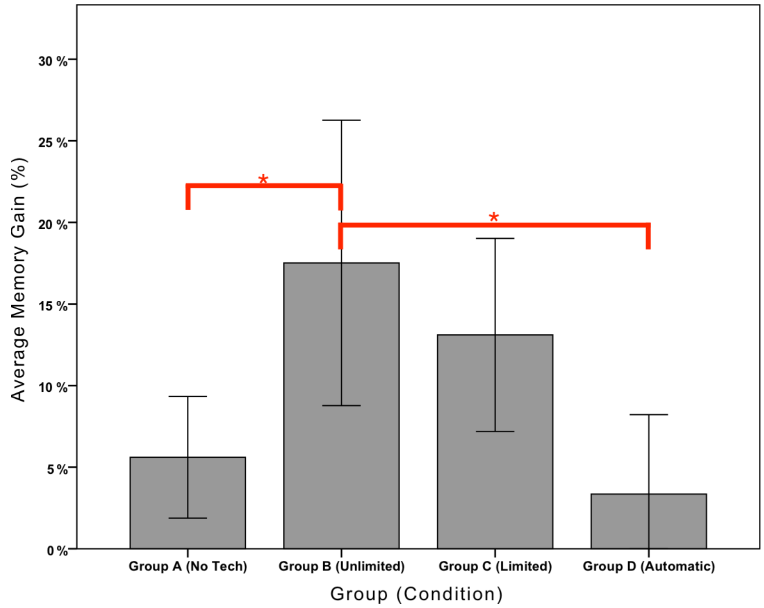

Fig. 6. Average memory gain (%) per group/condition after picture review. Pictures captured with smartphones' native camera app (Group B) supported recall significantly more than pictures captured automatically with Narrative Clips (Group D). Group A did not review any content and simply repeated an unassisted recall session. Statistically significant differences are marked with an asterisk for a value of $p < .05$.

the Narrative Clip. However, no significant difference was found between participants who reviewed pictures taken with MGOK (Group C), as opposed to participants who took pictures using smartphones (Group B) or the Narrative Clip (Group D) in terms of pictures' reported *memory aid*. These findings corroborate H2 in that manually captured pictures hold higher memory value than automatically captured pictures.

Participants of both groups that entailed active picture capture (i.e., Groups B and C) expressed equally divided views over the disruptiveness of picture capture. Some found active picture capture contributing positively to their concentration and engagement:

> "[P4] *I think the photo capturing device helped me be more engaged during the campus tour in that as I was deciding how to take the picture, what to include...* [P6] *I was more concentrated on the information.* [P16] *...definitely feel that having the camera made me feel more engaged in the Campus tour.* [P46] *I feel that the capturing device did help me engage more during the campus tour.* [P57] *It definitely did help me to be more engaged because I knew I can't be too dependent on it as I had limited storage for pictures* [P69] *I felt that being able to photograph places and items allowed me to better memorize some moments, as if I'd put a pin and the picture and leave it on a cork-board."*

Others found active capture disruptive:

> "[P5] *The mobile phone given was in fact kind of restricting the tour.* [P7] *taking pictures made me feel like I was drawing too much attention.* [P52] *I don't think the device helped me in engaging with the campus tour. It has only interrupted me more as I have to listen to what the researcher said but at the same time I have to take the pictures too. I found it hard to focus...* [P70] *...spent too much time concentrating on taking a photo. Forgot or didn't hear facts because I was making sure I got a picture.* [P71] *Taking photos made me listen less to the actual facts"*

Interestingly, some participants reported various capture strategies they developed or even changes in their behavior that helped them deal with the specifics of each condition they were undergoing for maximizing memory gain later. For example, a participant in Group B (i.e., unlimited capture) reported increased awareness between what was captured and what was said for improving later recall:

> "[P77] *The camera made me more aware of how I would view the objects later in order to remember what was being said"*

4.3 Limited Manual Capture Effect (H3)

One could attribute the significantly increased memory gain effect encountered in Group B to the unlimited number of pictures that participants could take. Expectedly, non parametric Moods Median tests displayed a significant main effect for condition type on number of pictures captured for conditions that entailed picture capture ($\chi^2(2) = 40.995$, $p < .001$). Post hoc pairwise comparisons using Pearson's chi square tests revealed that participants wearing the Narrative Clip (Automatic: *Mdn* = 106.5) captured a significantly higher number of pictures than participants who captured pictures with a smartphone (Unlimited: *Mdn* = 72) ($\chi^2(1) = 13.333$, $p < .001$, $V = .577$) and participants who captured pictures with the MGOK app (Limited C: *Mdn* = 24) ($\chi^2(1) = 41$, $p < .001$, $V = 1$) (see Fig. 7). Moreover, participants using smartphones captured a significantly higher amount of pictures than participants who used the MGOK app ($\chi^2(1) = 13.887$, $p < .001$, $V = .582$) (see Fig. 7).

Having found that "number of pictures" displayed systematic variations across all conditions, we next investigated its effects on memory loss and memory gain. We first computed Pearson product-moment correlation coefficients for assessing the relationship between number of pictures taken and reviewed with memory loss and memory gain, respectively. However, we found no significant correlation between either number of pictures taken and memory loss ($r = .072$, $p = .519$, $n = 83$), or between number of pictures reviewed and memory gain ($r = .039$, $p = .727$, $n = 83$). Nevertheless, we suspected a plausible confounding effect of number of pictures on memory gain for condition type. For this, we performed an analysis of covariance [18] with memory gain as a dependent variable and condition type as an independent variable, while controlling for number of pictures captured/reviewed. The analysis maintained the assumption of homogeneity of regression ($F(2,58) = 2.563$, $p = .086$) and still displayed a significant main effect for condition type for the condition types that involved picture capture (B, C and D), after controlling for the effect of number of pictures variable ($F(2,57) = 5.402$, $p < .05$, $\eta_p^2 = .159$). Post hoc pairwise comparisons using the Bonferroni correction revealed significant differences for the adjusted averages between groups B (Unlimited: $M = 16.197$ %, SE = 3.375 %) and D (Automatic: $M = - 2.098$ %, SE = 5.378, $p < .05$) but not between groups B and C (Limited: $M = 19.552$ %, SE = 5.99 %).

Despite influencing the effect of the condition type (i.e., B, C or D) on memory gain, the covariate number of pictures taken was not significantly related to memory gain per se ($F(1,57) = 1.595$, $p = .212$, , $\eta_p^2 = .027$). This indicates that the number of pictures taken (and subsequently reviewed) has influenced the improvement in participants' ability to better recall the campus tour one week after, across all three groups that involved picture taking. When controlling for the number of pictures, Group C (i.e., limited) displayed the highest average memory gain ($M = 19.552$ %, SE = 5.99 %) surpassing the other two groups that involved picture capture (i.e., B: $M = 16.197$ %, SE = 3.375 % and D: $M = - 2.098$ %, SE = 5.378 %), though not significantly (Fig. 8). In principle, this finding appears to be in line with our hypothesis (H3) in that the MGOK app would produce pictures of higher memory value, though this trend did not emerge significantly.

During picture review, participants agreed in principle that pictures taken actively (Groups B and C) helped them recall details about the campus tour:

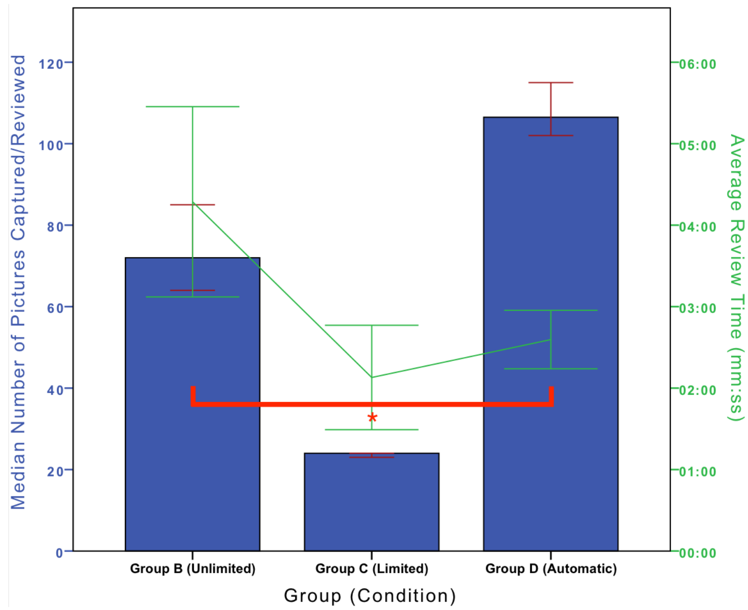

Fig. 7. Left axis: Median picture number per condition. Right axis: Average picture review time per condition. Participants with Narrative clips (Group D) captured significantly higher number of pictures overall but also spent significantly less time reviewing them than participants using the native camera app (Group B). Median number of pictures is statistically different for all conditions. Statistically significant differences for average review time are marked with an asterisk for a value of $p < .05$.

"[P28] *Of course the photos helped me remember the campus tour.* [P44] *I found the pictures really helped me in recalling the items that I forgot. The pictures also help me to remember items associated to the places.* [P19] *The camera did help, as I remembered more items from the first few locations that I photographed before they ran out.* [P69] *Some items were not very memorable. Having reviewed the item [picture], I can recollect where and when they were, but I did not spontaneously remember them."*

Some also mentioned that people caught in the picture helped them remember more, as previously shown [16]:

"[P37] *But the photo did help me remember the speaker ..."*

In particular, the imposed capture limitation appears to have forced participants to develop some strategy for improving later recall. Some, as we hypothesized, strived to capture important places/moments during the tour:

"[P53] *...by trying to take meaningful photos, which helped me to better remember the places and facts described."*

Some used to the capture limitation to face the "*recency effect*" [9] by capturing more pictures in the beginning of the tour and less/none towards the end:

"[P57] *I took pictures of everything in the beginning of the campus tour because I thought I would remember better of things that are recently shown and that I could refer to pictures that was taken earlier before."*

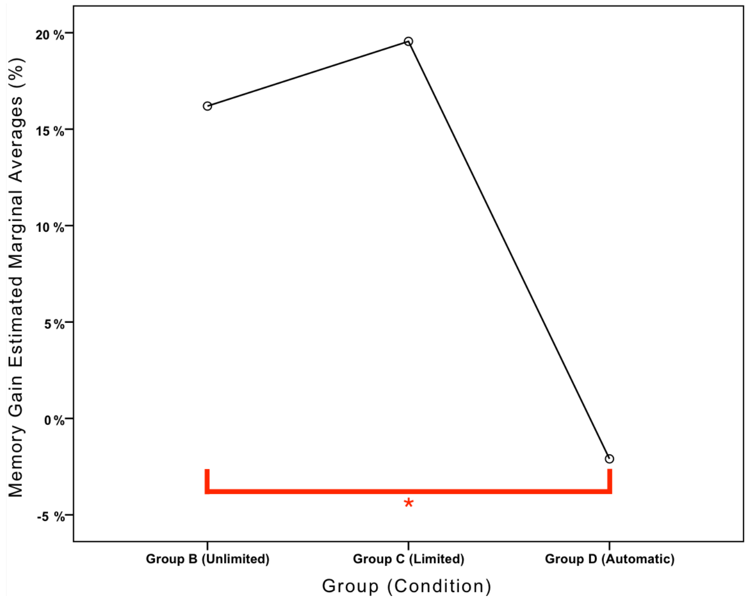

Fig. 8. Estimated memory gain for all condition entailing picture review when controlling for number of pictures captured. Statistically significant differences are marked with an asterisk for a value of $p < .05$.

Others regretted not having handled the limitation more efficiently:

"[P72] *Yes, but I should have been careful because of the limited number of pictures available and the larger quantity of places to remember; I should have taken pictures of the most difficult to remember."*

For some, picture capture with the MGOK app was perceived as a way to vividly imprint a scene in one's memory:

"[P74] *I remember a lot of places in the same way I took a picture. It seems like I have those pictures in my mind. This was extremely exciting."*

4.4 Unlimited Automatic Capture Effect (H4)

Although it was expected that the Narrative Clip would capture the highest number of pictures, we assumed that participants reviewing pictures captured via the Narrative Clip would also need significantly more time than all other participants. Nevertheless, an analysis of variance with picture review time in minutes as dependent variable and condition type as an independent variable displayed a significant main effect for condition type ($F(2,58) = 8.963$, $p < .001$, $\eta_p^2 = .236$). Post hoc tests using the Bonferroni correction revealed that participants reviewing Narrative Clip pictures (Group D: M = 2:35, SD = 0:46) needed in average significantly less time in contrast to participants reviewing pictures taken with smartphones (Group B: M = 4:17, SD = 2:29, $p < .05$), despite having significantly more pictures to review in average (see Fig. 4).

Moreover, non-parametric Moods Median Tests displayed a significant main effect both for condition type on S3: "*Ownership*" ($\chi^2(2) = 6.996$, $p < .05$) and S5: "*Semantic value*" ($\chi^2(2) = 18.523$, $p < .001$). For S3 "*Ownership feeling*", post hoc pairwise comparisons using Pearson's chi square tests revealed a significant difference in the medians between condition B (Mdn = 5) and D (Mdn = 2) ($\chi^2(1) = 7.03$, $p < .05$, $V = .419$) but no significant difference between condition C (Mdn = 4) and D (Mdn = 2) ($\chi^2(1) = 2.783$, $p = .095$, $V = .261$). This shows that during review, participants who took pictures with a smartphone reported a significant higher ownership feeling over their pictures as opposed to participants who reviewed pictures taken automatically with the Narrative Clip (H4). While a similar effect is observed between participants who reviewed pictures taken with MGOK app and participants who reviewed pictures captured with a Narrative clip, the difference is not significant.

For S5 "*Semantic value*", post hoc pairwise comparisons using Pearson's chi square tests revealed a significant difference in the medians between condition B (*Mdn* = 4) and D (*Mdn* = 2) ($\chi^2(1) = 18.027$, $p < .001$, $V = .671$) and condition C (*Mdn* = 4) and D (*Mdn* = 2) ($\chi^2(1) = 11.109$, $p < .05$, $V = .521$). This indicates that both participants who reviewed pictures captured with a smartphone and participants who reviewed pictures captured with the MGOK app, reported significantly higher *semantic gain* for these pictures, in contrast to participants who reviewed pictures taken with the Narrative Clip. This finding is aligned with H4 in that pictures captured manually (Group B and C) will be thought as more meaningful than pictures captured automatically (Group D).

In fact, participants of Group D (Narrative) did not favor the pictures to the same extent as those of Groups B and C:

> "[P22] *...but when I saw photos, they are not very meaningful.* [P23] *I don't think it helped me in remembering the things we saw, or in understanding the stories we heard better.* [P33] *Some of the pictures were helpful and some not, about half and half.* [P65] *Pictures provided doesn't help on the things that we need to remember."*

Instead, pictures captured with the Narrative Clip helped participants recall better the temporal order in which the places were visited:

> "[P49] *I thought that later I would be able to look at the photos and instantly remember every single detail. It turned out differently, I simply reviewed the order of locations, but I could not remember everything.* [P20] *Seeing the pictures helped aid my memory in terms of the order in which the places were visited, and also helped me remember the places I had visited."*

For the remaining statements (S4: "*Image quality*" and S6: "*Review engagement*"), series of non-parametric Kruskal-Wallis tests with S4 and S6 as dependent variables and condition type as independent variable displayed no significant main effect on S4 ($\chi^2(2) = 3.566$, $p = .168$, $\eta_p^2 = .059$) and S6 ($\chi^2(2) = 2.154$, $p = .341$, $\eta_p^2 = .035$) for the independent variable condition type. These findings did not confirm H4 in that pictures captured with the Narrative Clip will be rated as of significantly lower quality when compared with pictures captured with smartphones (Group B and C) and in that participants will be less engaged during reviewing Narrative Clip pictures (Group D).

Some participants mentioned positioning oneself in a way that helps capture the best picture with the Narrative Clip:

> "[P20] *I suppose I tried to position myself so that I took meaningful pictures, however, I could not be entirely sure I was managing to achieve this because I could not focus it like a camera."*

Others reported wearing the Narrative Clip was something that they even forgot about:

> "[P11] *The capturing device was of secondary importance.* [P30] *I felt indifferent however about the camera and would perform the same in the experiment without it.* [P31] *I did not behave differently to what I would have done if I was not carrying a device.* [P33] *I forgot I was wearing the camera.* [P81] *I didn't put attention on the device, most of the time I don't even notice it exists."*

Others mentioned that they became so reliant to the Narrative Clip that felt like carrying a “secondary brain”:

> [P49] *I think that the capturing device made me feel more confident in memorizing the information, because I thought that later I would be able to look at the photos and instantly remember every single detail... It helped me in being more engaged in the sense that it was like a second brain, i.e., if I missed something, the camera would surely capture it.* [P59] *I felt that I became reliant on the photo capturing device to help me with remembering what happened on the tour.”*

While some users blamed themselves for the lack of meaningful content captured with the Narrative Clip:

> “[P23] *In regard with the capturing device, I felt that I should be careful as I was taking photos automatically. When I saw the photos, they are not very meaningful, in fact I did not have an experience to manage to take better photos with the equipment.”*

5 DISCUSSION

Below, we discuss our findings grouped by *capture* and *review* perspectives, for explaining how each condition affected participants’ ability to recall the campus tour.

5.1 Memory Loss during Capture

We found that participants that used the MGOK app for capturing pictures during the campus tour displayed significantly greater memory loss a week later than participants who did not use any capture technology at all. However, this effect was far less pronounced for participants in either Group B (Unlimited) or Group D (Automatic). The introduction of a novel artifact (i.e., the MGOK app) with new features (e.g., capture limitation and focus to capture) may have distracted the participants more than those in Group B (Unlimited) who used a typical camera app throughout the campus tour. We were thus unable to confirm that the photo-taking impairment effect is due to disruption at encoding (i.e., participants relied on having external memory support so did not pay as much attention). However, when comparing Groups B&C (manual picture capture) with Groups A&D (no manual picture capture), we found significant differences both right after the tour and one week after the tour, lending credence to the explanation that the “photo-taking impairment” effect is due to the distraction caused by manual picture capture [12]. Interestingly, Group D (Automatic) did not display significantly lower memory loss when compared with Group C, as one would expect due to the unobtrusive capture fashion of the Narrative Clip. Some Group D participants reported that they “*tried to position”* themselves so that they could take *“meaningful pictures”*, indicating that they were similarly distracted during the tour as those taking pictures manually. As for the difference between Groups B&C, the findings showed that manual capture both in limited and unlimited conditions was equally intrusive. However, participants in Groups B and C did not report a lower engagement than those who did not actively take pictures (Groups A – No tech & D - Automatic).

5.2 Memory Gain during Review

We found that pictures captured with the native camera app (i.e., Group B - Unlimited) offered significantly higher memory gain than pictures taken with the Narrative Clip. The same does not hold for pictures captured with the MGOK app, as opposed to pictures captured with Narrative Clip or with the native camera app. However, when we controlled for the number of pictures captured (and subsequently reviewed), the analysis displayed higher memory gain for the pictures captured with the MGOK app, though not significantly higher. Moreover, participants rated their feeling of ownership and semantic gain higher for MGOK pictures than they did for Narrative Clip pictures. The higher memory gain shown for MGOK may be due to the imposed capture limitation that possibly led participants to capture more important moments, as we had hypothesized. However, further investigation is needed to reliably confirm this claim.

We discovered that reviewing Narrative Clip pictures did not provide any significant memory aid for the participants in Group D. Narrative Clip pictures were reported as holding systematically less memory aid, less ownership, and less semantic gain than pictures captured with the native camera app. In addition, while participants in Group D (Automatic) captured significantly higher number of pictures in comparison to all other conditions, they also took significantly less time to review them than participants who manually captured pictures with the native camera app (Group B - Unlimited). In fact, participants in Group D (Automatic) spent in average only 28 seconds longer for reviewing in average the quadruple number of pictures that participants in Group C (Limited) reviewed. These findings showcase that periodic automatic capture falls short in producing pictures that can effectively assist remembering. Furthermore, participants were in general disappointed with the pictures captured by the Narrative Clip and even accused themselves at times for not being experienced or not operating it appropriately. As reported, they used the pictures for eliciting the temporal order [5] of the places visited and thus, recall any details about the campus tour. Interestingly though, no significant differences were found on perceived image quality and quantity across all conditions, as we assumed beforehand.

5.3 Study Limitations

Participants in the study knew that the purpose of the experiment was to test memory, and therefore their aim was to utilize any means (if any) at their disposal for maximizing their recall at a later stage. While this is a typical experimental setting in memory psychology research, we usually do not aim to "maximize recall" in our day to day activities, hence one may question the ecological validity of the results. However, conscious attempts to remember our activities are still prevalent in our daily lives, from memorable events such as birthdays or reunions, to recreational activities such as museum visits, to busy days in the office. We also acknowledge that our study focused only on one particular aspect of lifelogging – the recollection of past experiences (episodic memory). However, as Sellen and Whittaker [25] described, lifelogging systems may have a wider range of benefits, which they summarized as the "Five Rs": Recollecting, Reminiscing, Retrieving, Reflecting, and Remembering Intentions. Our study does not provide insights on how well automated capture systems such as the Narrative Clip could support these other benefits.

During the various campus tours we administered, we noted several times that participants in Group C – the MGOK camera app – struggled with the unusual "hold-to-focus; release-to-shoot" shutter button functionality. This may have negatively influenced their memory scores as the act of taking a photo was more distractive than using a regular camera app. Equally influential might have been the choice of allowing only 24 photos – a slightly larger number (e.g., 36) might have still challenged participants to be selective in their picture-taking, yet supported a broader set of images. We also did not control for participants' experience in taking pictures with a mobile phone in general – less experienced participants might have equally been unable to follow the information offered by the tour guide while taking a photo. However, our participants' age (M = 25.301, SD = 8.849), as well as the fact that all of them owned a smartphone, suggests that all of them were reasonably familiar with smartphone image taking. Finally, we also did not control for participants' prior knowledge of the campus, which may have favored some to be better able to remember individual items. However, by adding seldom known facts about each of the presented items, we expect that even those familiar with the campus had a wealth of new information that had to be remembered.

5.4 Implications and Future Work

We believe that our work can contribute to the design of future wearable memory augmentation systems with respect to the idea of using wearable cameras as a replacement for manual picture taking. The "photo-impairment effect" would posit that wearable cameras offer less memory distraction, hence improve active memorization of events. The artificial limit on the number of photos taken offered another point in the design space, questioning if fewer, more "thoughtfully" taken pictures may lower this photo impairment. Our findings suggest that the quality of current generation wearable cameras does not yet live up to this promise, and that we require novel ways of capturing meaningful memories in a non-distractive fashion. Also, the fact that the wearer is not included in the captured pictures may limit the value of such images for recalling episodic memories. Bexheti et al. recently proposed a system architecture for automating the sharing of lifelogging images for co-located peers [2].

In future work, we plan to continue our trials towards investigating the added value of lifelogging images for human memory in later stages of recall (i.e., a month or a year after an experience). We believe that lifelogging cameras hold a potential for augmenting one's memory recall under certain conditions. For example, the need for selectivity and not total capture is one direction we are currently investigating [25]. In particular, we are investigating if a range of biophysical responses (e.g., heart rate) as measured by wearable sensors (e.g., a smart watch) could indicate moments of increased significance or increased memory value for informing the capture or display of specific lifelogging content [22,23].

6 CONCLUSION

In this work, we contrasted limited, unlimited, and automatic picture capture in augmenting memory recall. We could confirm that manual picture capture may lead to the encoding of memories of lower quality. Contrary to Nightingale et al. [26], we thus confirmed Henkel's “photo-taking impairment” effect [12] and attributed it to the act of picture capture, not external memory support [27,28]. We also found that automated capture as offered by today's wearable lifelogging cameras produces pictures that hold only a low potential in improving one's ability to remember a prior experience. While our participants exhibited various behaviors and techniques in an effort to handle an imposed capture scarcity (when using the “My Good Old Kodak” Camera App), limited capture did not improve their recall significantly, while unlimited capture did increase it significantly.

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