Technology Mediated Memory: Is Technology Altering Our Memories And Interfering With Well-Being?

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Technology increasingly allows us to capture and revisit rich digital records of our lives, processes which we call Technology Mediated Memory (TMM). We explore whether TMM alters unmediated remembering and also whether such changes affect psychological well-being. Human memory biases promote well-being by adaptively editing our memories, making them more positive. In contrast, TMM often provides rich records of what people *actually did and felt,* which could disrupt adaptive edits. To explore this, we developed a smartphone-based personal TMM application, Echo, that allows participants to record and later reflect on everyday events. In a month-long deployment, 64 users made over 3200 recordings and reflections. We found that although Echo TMM alters how we remember, these changes remain adaptive. Instead of compromising adaptive biases, Echo TMM helps well-being and benefits are sustained long-term. Logfile analysis shows that participants use Echo strategically to *prospectively edit* by initially reporting events positively to anticipate future viewing. Participants also distance themselves from past negative events by reflecting more positively than at recording. We discuss design and theoretical implications.

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1. INTRODUCTION

The film *Eternal Sunshine of the Spotless Mind* [Gondry 2004] takes place in a near-distant future and details the story of two characters who use technology to permanently erase unwanted memories. This of course becomes a terrible mistake as the characters struggle to hold on to their cherished pasts, however painful they were. In reality, we don't have the power to erase our own memories, but technology may now provide us with the opposite opportunity. Technology is now supplementing our unaided 'organic memories' by providing rich *technologically mediated* records of our pasts. This paper explores whether Technology Mediated Memory (TMM) is fundamentally changing how we remember and whether this affects well-being.

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Autobiographical memory is an organic system that encodes, stores, and retrieves personal memories from our lifetime. TMM, on the other hand, is any technology that also encodes, stores, and retrieves autobiographical information. TMM allows people both to externally store digital memories by recording personal information (which we call *TM-recording*), and to retrieve this personal information later for active review (which we call *TM-reflection*). Some TMM systems emphasize TM-recording, as exemplified by lifelogging (e.g. MyLifeBits, UbiqLog), where the focus is on capturing a complete record of our lives. Others focus on TM-reflecting (e.g. Pensieve, Timehop), exploring how we use records of our past both to reminisce but also to better understand ourselves. However, by definition a TMM system must contain both components, supporting recording to capture digital records that may be revisited later for reflection.

One extreme viewpoint is that TMM technologies will provide 'total recall', generating complete records ('lifelogs') of everything we experience and feel [Bell and Gemmell 2009]. Although there have been critiques of the lifelogging approach [Sellen and Whittaker 2010], part of this vision is already with us, as we increasingly live more of our lives online. Everyday social media technologies now routinely allow us to post photos and view past status updates in ways that are potentially transforming our memories. Facebook Timeline and new reflective systems such as Timehop and MorningPics make it easier to review rich multimedia records of our everyday activities.

This paper both evaluates whether TMM alters the *ways* that we remember, and also whether this has *consequences for psychological well-being*. Do we benefit from revisiting rich digital records of our past, or are some details best forgotten? This is an important question because psychological theories show that everyday organic memory presents a non-veridical view of our past that benefits our well-being. Organic memory has four different strategic biases. First, people tend to remember more positive than negative events [Walker et al. 2003]. Second, negative details of individual events are forgotten more than positive details [Mitchell et al. 1997]. Third, there is an emotional asymmetry in the time course of past events with negative affect fading more rapidly than positive affect [Walker and Skowronski 2009]. Finally, the ways that people view past events becomes less self-focused over time, indicating adaptive distancing from negative experiences [Campbell and Pennebaker 2003; Rude et al. 2004].

Adaptive memory theories argue that these organic memory biases enhance well-being by inducing a more positive view of our pasts [Conway and Pleydell-Pearce 2000]. But TMM may threaten such adaptive biases by showing us detailed unedited records of *what we actually did and felt*. This paper therefore examines whether these new rich technologically mediated records *interfere* with adaptive biases, preventing us from adaptively editing our pasts. Furthermore, we also explore the underlying mechanisms by which TMM affects well-being. Specifically we compare two aspects of TMM. Both aspects may affect well-being and we explore the effects of each. We compare the process of initial event *recording* (TM-recording) to recording with later *reflection* on that event (TM-reflection). TM-reflection systems necessarily presuppose TM-recording to generate data for reflection. However for concision in this paper we use the term TM-reflection to refer to the *combination* of both, i.e. recording with reflection. Additionally, comparing recording alone (TM-recording) against

recording with reflection (TM-reflection), allows us to isolate whether actively reviewing past records has any exclusive benefits.

To address effects of TMM on memory and well-being, we designed and deployed a smartphone-based TMM application called Echo [Isaacs et al. 2013] in a field trial involving 64 participants. While there exists a broad range of different TMM systems, Echo was designed to represent a significant subset of them. Echo targets *personal memory* rather than the sharing of events supported by social media applications. It affords straightforward *recording* of everyday events using photos, audio, and text, allowing participants to actively create rich daily event entries, along with *emotional ratings* for those entries. Echo also supplements organic memory by presenting prior recordings back to participants prompting those participants to actively *reflect* at a later time. We evaluated the effects of using Echo on well-being in a month-long intervention, and followed up with participants four months later to examine long-term effects. We address the following questions:

— Does recording and reflecting on detailed autobiographical Echo records alter well-being compared with organic memory?
— Does Echo TMM change remembering processes? Does Echo TMM compromise the adaptive biases of organic memory, or reinforce them?
— What are the mechanisms by which Echo TMM affects well-being?
— Are there additional well-being benefits to TM-reflecting over TM-recording alone?
— What are the long-term effects of Echo TMM on well-being?

2. RELATED WORK

2.1 Basic Functions and Biases of Autobiographical Organic Memory

There is an extensive literature regarding the development, characteristics, and functions of organic autobiographical memory [Conway and Pleydell-Pearce 2000; D'Argembeau and Van der Linden 2008; Rubin et al. 1998; Walker et al. 2003]. Here we focus on how autobiographical memory functions and whether technology might interfere with natural remembering processes. The three primary functions of autobiographical memory are: directive, social and self-consistency [Bluck et al. 2005; Pillemer 1992].

Directive functions plan and direct our future behaviors. Analysis of past autobiographical memory experiences helps us to learn from our past failures and successes, allowing us to strategically plan future behaviors. Cohen [1996] argues that autobiographical memory can serve as an aid to learning, allowing us to ask new questions of old information, to solve problems in the present as well as predicting future events.

Social functions involve disclosing elements of one's past to others to promote interpersonal relationships. Personal memories become material for conversations, which develop and nurture social bonds [Bluck et al. 2005; Williams et al. 2008]. Reflecting on past autobiographical memories also motivates people to solicit social support [Kim 2008; Pennebaker et al. 1989]. Using memory to strengthen social bonds has clear well-being benefits and is considered to be evolutionarily adaptive [Neisser 1988; Rook 1985; Silk et al. 2003].

A third function is *self-consistency*, where we remember our pasts to maintain self-coherence across time. Our memories are important to preserving and enhancing our identity. Threats to this coherence are adaptively edited to preserve our self-image [Conway and Pleydell-Pearce 2000]. We seek a positive sense of self so that discrepancies are biased towards self-enhancement [D'Argembeau and Van der Linden 2008]. If memories conflict (such as emotionally positive and negative memories for the same event), then we retain the positive memory and edit or even entirely forget the negative memory [Mitchell et al. 1997]. This adaptive focus on self-enhancement is manifested in multiple organic memory biases, including *positivity*, *rosy retrospection, fading affect bias* and *distancing*.

2.1.1. Positivity. There is a consistent bias towards recording and remembering *positive* rather than negative events [Walker et al. 2003]. Walker reviews 8 diary studies where people record events as they happen. These studies reveal a positivity bias: 59.5% of reported events were emotionally positive, 14.7% neutral, 25.8% negative [Thompson et al. 1996]. This bias occurs across multiple studies using very different methods [Berntsen 1996; Chwalisz et al. 1988; Suedfeld and Eich 1995; Waldfogel 1948]. In a meta-review Walker et al. [2003] found that people remember twice as many positive (50%), as negative events (25%), with the remainder being emotionally neutral.

2.1.2. Rosy Retrospection. Not only do positive memories outnumber negative memories, but people also adaptively edit the *content* of individual memories to make them more positive over time. During recall, people excise negative aspects of past events so they remember their past more positively than their actual experience at the time [Mitchell et al. 1997]. This bias is called *rosy retrospection*. For instance, in thinking about a past vacation at Disneyland, the actual experiences of long lines, mediocre food and crying children are naturally and adaptively forgotten, leading to a more positive view of the vacation.

2.1.3 Fading Affect Bias. Additionally, the *affective evaluation* of events fades over time in an adaptive way. People's emotional evaluation of past events attenuates, becoming less extreme over time. We may be ecstatic the day we win a promotion but evaluate that event less positively as time passes. The same is true of negative events, with major disappointments being progressively evaluated less negatively over time. However there is an *asymmetry* in this process, with negative events attenuating more rapidly. In other words, negative events regress to the mean more quickly than their positive counterparts [Walker et al. 2003]. This is called the *fading affect bias*. Rapidly reducing the impact of negative events while preserving the impact of positive events serves a self-enhancement function by maintaining well-being [Walker and Skowronski 2009].

2.1.4. Distancing. When people experience emotional or physical pain, their attention tends to be self-focused, and this is reflected in their language use. For example, depressed people use more first-person pronouns [Niederhoffer and Pennebaker 2002; Rude et al. 2004]. Furthermore, shifting from first-person to third-person descriptions of events over time promotes health improvements [Campbell and Pennebaker 2003]. Those who do not shift from self-focus display

static thinking patterns and experience poorer health outcomes [Francis and Pennebaker 1992; Nolen-Hoeksema et al. 2008].

2.1.5 Individual Differences and Rumination. In addition to these biases, there are also individual differences in emotional regulation, including how we construe and manage our evaluations of past events. One maladaptive style called "rumination" is characterized by a *lack* of adaptive self-editing. Ruminators do not adaptively edit but instead they repetitively and passively focus on the *symptoms* of a distressing event, such as their negative emotions (e.g. 'I feel so sad, I just can't concentrate'), rather than possible *solutions* [Nolen-Hoeksema 1991]. This exclusive focus on symptoms can be detrimental to health, leading to depression and anxiety [Nolen-Hoeksema et al. 2008]. Lyubomirsky et al. [2006] demonstrated the serious implications of this emotional style; breast cancer ruminators report their initial symptoms to a doctor 2 months later than non-ruminators with matched symptoms.

Rumination involves repetitive focus on negative events that would normally be edited or forgotten. One concern is that detailed TMM records might reduce adaptive forgetting by interfering with adaptive biases. By accurately re-presenting past events TMM may act like rumination, triggering perseveration on events that might be better forgotten. Studies of relationship break-up suggest that rich digital media may hinder adaptive forgetting. For instance, the ease of re-accessing online information about an ex-partner may compromise forgetting [Sas and Whittaker 2013]. On the other hand, providing detailed information about our pasts can be beneficial when it helps us re-appraise [Nolen-Hoeksema et al. 2008; Segal et al. 2012; Teasdale et al. 1995]. Thus, accessing detailed TMM records may actually *improve* thinking quality by providing rich information to reduce rumination, and increase overall well-being.

We now turn to studies that explore unmediated recording and reflecting. By unmediated we mean that these styles of recording and reflecting do not employ technology to help facilitate the process. We distinguish between unmediated *recording* and *reflecting*.

2.2 Unmediated Recording and Reflecting

2.2.1. Recording. Pen and paper based recording of everyday experiences has psychological benefits [Boehm and Lyubomirsky 2009; Jose et al. 2012; Pennebaker et al. 1997]. There are two possible reasons for this. Recording positive experiences increases subjective well-being because it enhances awareness and emotional intensity of positive aspects of life [Boehm and Lyubomirsky 2009; Bryant and Veroff 2007; Jose et al. 2012]. Such recording is called *savoring*. Recording negative experiences also increases subjective well-being by facilitating analysis of events and emotions [Pennebaker et al. 1997]. This analysis allows the negative event to be better understood which reduces its emotional intensity [Smyth et al. 2001]. This type of recording is called *emotional disclosure*.

2.2.2. Reflecting. Reflection involves mentally reviewing our memories of past experiences. Pen and paper based reflection is beneficial for both physical and psychological health. Somewhat counter-intuitively, reflecting on negative events is adaptive for well-being. The *expressive writing* paradigm [Pennebaker

and Beall 1986] explored the effects of reflection about negative events by having participants repeatedly write about past traumas. The procedure is different from TM-reflection, as participants write about events without access to detailed records from their past. A meta-analysis of 13 expressive writing studies revealed high effect sizes of improved well-being (mean weighted effect size of d=.47) [Smyth 1998]. However, the exact *mechanism* for the success of expressive writing remains unclear. One possibility is that expressive writing is effective because it allows people to distance themselves from past traumas and construct 'redemption sequences' [Pennebaker 2004; Wildschut et al. 2006]. A redemption sequence is a shift in perception of a past negative experience to a more positive, triumphant evaluation.

Having summarized how organic memory functions, its adaptive biases, and unmediated recording and reflection, we now review systems built to mediate memory. Again, we distinguish between *recording* and *reflection* activities in TMM. We first review TM-recording technology that allows people to capture detailed records of events in the moment. We then review TM-reflection systems that support revisiting those records and actively reflecting on them.

2.3 Technology-Mediated Recording and Reflecting

The affordances of technology mean that TM-recording and TM-reflection are quite different from unmediated recording and reflection. First, TM-recording and TM-reflecting can be more accessible and convenient as they are typically facilitated by a mobile phone or wearable technology. Their mobility makes TM devices more likely to be on the user's person than a pen and paper journal when recordable events occur. TM systems can also store rich content in one place, aggregating diverse media sources (e.g. pictures, video, audio, text), and organizing data (chronologically, by media type, or clustering events to allow repeated reflections on the same event). Technology also provides opportunities to remind users via alerts to record or reflect. It can automatically select records for reflection using different criteria (such as a memory that occurred exactly one year ago). Furthermore, unmediated reflection (such as with expressive writing) typically occurs without detailed records of the actual event, whereas technology captures rich records for later reflection.

2.3.1. TM-recording. There are many systems that afford straightforward 'in the moment' recording of events. Although text messaging, instant messaging, and emailing are commonly used for communication, they also provide ways to capture experiences and share them with others. Online journals and blogs also facilitate detailed rich descriptions of events, whereas microblogging systems (such as Twitter, Tumblr, Plurk, Twister etc.) support brief textual logging. Social media are now ubiquitous and have become a standard method for checking-in or creating posts about personally experienced events [Rose and Webster 2011]. There are also many new systems that are specifically designed to facilitate recording of everyday events. Lifelogging systems such as DayOne, Momento, HeyDay, Saga, MyLifeBits, UbiqLog, SenseCam, and Narrative Clip (formerly Memoto) capture rich records of everyday activities, exploiting wearable cameras or mobile phones [Gemmell et al. 2006; Hodges et al. 2006; Kalnikaite et al. 2010; Kalnikaite and Whittaker 2010; Rawassizadeh et al. 2012]. These systems improve memory and self-efficacy in Alzheimer's patients [Browne et al. 2011]. Furthermore, blogging events throughout the day is beneficial to subjective well-being [Ko and Kuo 2009; Nardi et al. 2004].

TM-recording technologies can be classified along three dimensions. The first is that they record either actively or passively. For example, online journals, blogs, microblogging, and social media require the user to *actively* create records by generating content. Conversely, lifelogging supports *passive* capture both to reduce participant recording burden and increase the scope of recorded information [Bell and Gemmell 2009]. While lifelogging systems such as Saga strive for entirely passive capture, most still require non-trivial user involvement during capture and curation [HeyDay, Momento, MyLifeBits, Sellen and Whittaker 2010]. For example, even passive acquisition systems like MyLifeBits encourage users to enrich passive data with personal notes, pictures, and video to facilitate retrieval.

A second characteristic of TM-recording is that information can be captured either *selectively* or *comprehensively*. Once again lifelogging differs from other TM-recording systems by attempting comprehensive capture of a full range of personal information. One criticism of early lifelogging systems is that they overgenerate minutiae, burdening people with potentially useless information [Petrelli and Whittaker 2010; Petrelli et al. 2008]. Newer lifelogging systems are characterized as supporting *personal informatics* to emphasize improvements over past approaches. Personal informatics systems attempt to capture only personally relevant information, and are selective in their recording [Li et al. 2010]. Thus more recent TM-recording systems tend to privilege selective capture.

Lastly, TM-recording can capture personal information from a diverse set of media sources. For example, online journals and blogs emphasize the capture of textual information, whereas Sensecam is primarily picture-based. More complex TM-recording systems like MyLifeBits capture text, pictures, audio, and video along with other media.

While it is possible with these systems to revisit and reflect on TM-recordings, their primary focus is on capture. The burden is on the user to search through records and initiate reflection. Next we explore systems that are designed specifically for TM-reflection, often through structured prompts and programmatic selection of records for reflection.

2.3.2. TM-reflecting. Many commercial systems support *review* of digital recordings of our pasts. Such reflections are usually system-driven, e.g. through emails or phone notifications, or by directing the user to a home screen. In contrast, while reflection is possible with TM-recording systems, these systems require that users actively search to enact their reflections. Some TM-reflecting systems such as Timehop, Live Happy [Parks et al. 2012], MorningPics, and 1 Second Everyday, send back past records for reflection after time has passed. Other tools such as PosiPost Me [Kanis and Brinkman 2010], IRateMyDay, MobiMood [Church et al. 2010], and eMoto [Fagerberg et al. 2004] add a social component to TM-reflection by sharing emotional data with friends. Facebook has also explored TM-reflection on past posts with Year in Review, Timeline Movie Maker, Lookback videos, Friends Day videos, Say Thanks, and On This Day. Google is offering similar services with Rediscover This Day. And even Spotify has offered reflection on songs users have listened to with Year In Music. One of the best studied TM-reflection systems is Pensieve, where a systematic

research program has explored different aspects of using technology for reminiscence [Cosley et al. 2009; Cosley et al. 2012; Peesapati et al. 2010]. Early explorations began with very simple impersonal prompts ('some of the nicknames that you've had') many of which were successful in engaging users and promoting reminiscence about past events. A second iteration extended these features by linking to the user's social media, photo and music sites. These media were then used to prompt reflection, e.g. a photo or song from the user's collection might be accompanied by the prompt 'do you remember?'. Although social sharing of reflections was not successful [Cosley et al., 2012], other aspects of the system were used extensively. Participants reported that they enjoyed the reflective process and that it improved their mood. Reflections were generally found to be positive, although the nature of the prompt affected this [Peesapati et al. 2010].

Overall, TM-reflection systems vary along different dimensions. First, because TM-reflection requires digital records, each TM-reflection system's characteristics partially mirrors its TM-recording features. For example, if system capture is passive and comprehensive, there will be a larger pool of data for the system to sort and select for reflection. More typically, TM-reflection systems are based around active, and selectively created TM-recordings, to make reflections personally meaningful (e.g. Timehop, 1 Second Everyday, PosiPost Me, MobiMood).

Additionally, reflection can either be *structured* (i.e. through writing) or *unstructured* (i.e. thought about mentally). Structured TM-reflection systems encourage the user to write about the memory (e.g. Pensieve, Live Happy), whereas unstructured systems often have an option for written reflection, but without directly encouraging users to do so (e.g. Facebook's On This Day, Timehop). Thus reflective writing is typically available for TM-reflection, though not always encouraged.

We designed our smartphone application, Echo, to embody many of these typical TMM features. Thus Echo facilitates recording that is active, selective and provides common options for capturing media sources (e.g. text, audio, pictures). Echo also supports prompted reflections that are structured through writing.

2.4 Intervention Design and Research Questions

TMM may promote psychological well-being through adaptive self-enhancement functions. TM-recording may help keep positive events positive (through savoring) and ensure negative events are processed more quickly (by structuring a better understanding of the event). TM-reflection may help reduce self-discrepancies through redemptive shifts in self-perception. Alternatively, TMM may interfere with adaptive shifts in perspective because one's initial perspective at the time of the event is directly accessible through detailed records. Furthermore, the processes of savoring and disclosing events during recording may be intentionally altered by TMM users who anticipate reflecting on these recordings via technology. These concerns led us to explore the effects of TMM on memory and well-being, to determine whether TMM interferes with adaptive processes.

Prior work [Isaacs et al. 2013] has demonstrated the well-being benefits of using Echo for both TM-recording and TM-reflecting. The current paper investigates different questions about the contrasts between TMM and organic memory and their relations to well-being, presenting new data specific to these questions. Additionally, this paper presents two additional sets of field trial participants and a long-term follow-up study, both of which were collected since the Isaacs et al. [2013] paper.

We conducted a field trial intervention with our novel smartphone system, Echo. We also followed up with participants to explore long-term well-being effects. Participants were allocated to one of 4 conditions that involved different ways of using our system. There were two experimental groups that explored different aspects of TMM. The *TM-recording* group simply recorded three or more events per day, but never revisited those events. The *TM-reflecting* group not only recorded, but also *reflected* on three or more past events per day that the system presented back to them. There were also two controls: the *no-technology control* simply participated in the study with no intervention, and the *technology control* used Echo to record three neutral events each day.

These two control groups addressed Hawthorne effects and subject-expectations. The Hawthorne effect states that simply participating in a research study about well-being may be enough to bias well-being responses. The *no-technology control* group did not use Echo, but completed the same well-being surveys a month apart. This should provide us with a baseline that captures effects resulting from participating in a well-being study. These controls should think about their pasts in the regular organic way, and have the normal adaptive memory biases. However, it is also possible that TMM participants expected their well-being to improve because they were given new technology and spent a month working with the software. To control for these different subject-expectation effects, we ran a separate *technology control* group where participants used Echo to record only events that were *emotionally neutral,* such as describing a visual pattern in their environment. These participants would not be able to savor positive events or disclose negative events, and so any benefits received would result from subject-expectation effects.

In each of the 4 conditions, we measured the *effects of our Echo TMM intervention on well-being* by assessing changes across four widely-deployed well-being surveys administered before and after the intervention. These surveys were: Subjective Happiness Scale [Lyubomirsky and Lepper 1999], Satisfaction with Life Scale [Diener et al. 1985], Psychological General Well-Being Scale [Dupuy 1984], and Mindfulness Attention Awareness Scale [Brown and Ryan 2003]. We describe these in more detail below. We used 4 surveys to triangulate different aspects of well-being, because there is no definitive measure of well-being [Seligman 2012]. These surveys therefore assess positive affect (Subjective Happiness Scale), global cognitive evaluations of one's life (Satisfaction with Life Scale), perceived quality of life (Psychological General Well-Being Scale), and awareness (Mindfulness Attention Awareness). We evaluated both short and long-term well-being effects by administering surveys immediately after our one-month intervention and again after 4 months.

We also wanted to explore whether memory is altered by Echo TMM and whether there were consequences to such alterations. Specifically we examined whether *Echo TMM showed typical adaptive biases* and determined *whether and how Echo TMM affected well-being*. In addition to gathering emotion ratings about each recording and reflection, we also conducted content analysis on participants' daily *records* and, where relevant, their *reflections* on those events. We used LIWC (Linguistic Inquiry Word Count) [Pennebaker et al. 2007] to automatically analyze the text in people's logfiles. LIWC is an efficient, effective, and widely used lexical analysis tool that automatically classifies words according to their semantic category. It has good internal reliability and external validity when compared with human judges [Kahn et al. 2007; Pennebaker et al. 2007; Pennebaker and Francis 1996; Tausczik and Pennebaker 2010]. LIWC allowed us to determine whether Echo TMM showed adaptive biases by analyzing: positive and negative affect words, future vs present focus, words referring to relationships, and distancing effects as indicated by personal pronouns. This content analysis specifically examined: (a) positivity bias – reporting more positive than negative events overall, (b) rosy retrospection and fading affect bias in reflections compared with recordings, (c) greater distancing as evidenced by fewer personal pronouns, and (d) evidence of the three organic memory functions in TMM (directive, social, and self-consistency). Finally we examined whether these adaptive biases improved well-being.

Our specific research questions were:

RQ1: Compared with organic memory does Echo improve or interfere with well-being? On the one hand, recording and reflecting on detailed records in Echo might compromise adaptive biases. Unlike organic memory, Echo participants might find it hard to adaptively edit detailed digital records of their pasts leading to decreased well-being. On the other hand, Echo might help; unmediated *recording* increases well-being through savoring and emotional disclosure and unmediated *reflection* facilitates redemption narratives and distancing.

RQ2: Are there differences between TM-reflecting and TM-recording in promoting well-being? To further understand *underlying mechanisms* we examined the separate contributions of recording versus reflection. We expected TM-reflectors to have more extreme well-being changes (whether positive or negative). If TMM compromises adaptive biases, then TM-reflection will *decrease* well-being because TM-reflectors are re-presented with detailed digital records leading to possible self-discrepancies with their prior organically recalled experiences. On the other hand, if TMM preserves biases, we expect greater *benefits* for TM-reflection. TM-recorders have a single opportunity of savoring/disclosure but never revisit their records. In contrast TM-reflectors both create records and later revisit these. We also expected TM-reflectors to make more positive recordings because they anticipate reflecting on these in the future.

RQ3: Does Echo TMM alter fundamental adaptive biases and functions that characterize organic memory? We examined the *content* and *emotion ratings* of recordings and reflections to determine whether Echo participants show typical adaptive self-enhancement biases found in organic memory: positivity, rosy

retrospection, fading affect bias and distancing. We were also interested in whether Echo TMM displayed typical directive and social functions that are evident in organic autobiographical memory.

RQ4: What are the long-term effects of Echo TMM on well-being? Finally we explored the *longevity* of well-being benefits across time. Other research suggests that optimal expressive writing benefits happen several months after such reflection has taken place [Pennebaker et al. 1997]. We therefore measured well-being effects 4 months after our intervention to compare long-term Echo benefits compared with unmediated studies.

Sections 3 and 4 describe a one-month intervention that addressed RQs1-3, and Section 5 a long-term follow-up that addressed RQ4.

3. INTERVENTION: EVALUATING THE EFFECTS OF ECHO TMM ON WELL-BEING AND ADAPTIVITY

3.1 Method

3.1.1. Participants. Altogether 64 participants, 36 of whom were female, completed the study. Participants were aged 18 to 63 (M= 25.44, SD= 9.82). See Table I for a breakdown of how many participants were in each group.

Table I. Number of participants who completed the one-month study

Group	N
TM-recorders	17
TM-reflectors	16
Technology control	16
No-technology control	15
Total	**64**

All participants were told that the study addressed self-reflection and well-being. We recruited participants in two batches. The first batch were recruited through local flyering and online advertisements (through Facebook, UC Santa Cruz email lists and Craigslist). They were not offered any compensation, and each participant was randomly assigned to one of the Echo TMM groups. This allowed us to recruit 38 participants of whom 5 were removed because of technical issues or they withdrew from the study. We recruited the technology control group the same way; 44 participants were recruited of whom 28 dropped out (primarily due to losing interest in neutral recording). Lastly, the no-technology control group was recruited through the UC Santa Cruz psychology research pool; 15 students participated with no dropouts. Note that while all participants completed the well-being surveys, 4 TM-recorders chose not to share their logfiles of individual recordings with us.

3.1.2. Surveys. Well-being was assessed at pretest and posttest using four standard well-being scales. All scales are widely used and have high discriminant and convergent validity and test-retest reliability in multiple populations. The scales were intended to assess different aspects of well-being,

including positive affect and flourishing, long-term evaluations and meaning, affect and quality of life, and awareness.

Subjective Happiness Scale (SHS). The SHS consists of 4 items that assess global subjective happiness using absolute ratings, as well as ratings of self relative to perception of others [Lyubomirsky and Lepper 1999]. Participants evaluate their general happiness levels rather than how happy they have been across any specific time period. An example item is, "Compared to most of my peers, I consider myself…" which has response categories ranging from "less happy" to "more happy."

Satisfaction With Life Scale (SWLS). The SWLS consists of 5 items to assess satisfaction with life as a whole [Diener et al. 1985]. Participants assess general satisfaction with life without focus on a specific time period. SWLS does not query participants about different life domains but allows participants to weigh those domains overall. An example item is, "If I could live my life over, I would change almost nothing."

Psychological General Well-Being Index (PGWBI). The PGWBI is a 22-item questionnaire to measure "self-representations of intrapersonal affective or emotional states reflecting a sense of subjective well-being or distress" [Dupuy 1984]. The PGWBI is often used in clinical trials as a measure of health-related quality of life. Participants assess psychological general well-being over the past month specifically. An example item is, "I felt cheerful, lighthearted during the past month," which has response categories ranging from "none of the time" to "all of the time."

Mindfulness Attention Awareness Scale (MAAS). The MAAS consists of 15 items to assess individual differences in "the presence or absence of attention to and awareness of what is occurring in the present" [Brown and Ryan 2003]. Higher scores are correlated with, and predictive of, well-being and emotion regulation phenomena. Participants assess general mindfulness without focus on a specific time period. An example item is, *"I find it difficult to stay focused on what's happening in the present."*

Echo System. We developed a personal memory smartphone application Echo to allow participants in the two TMM conditions and the technology control to make daily records, and in the case of the TM-reflecting group to revisit these records later [Isaacs et al. 2013]. Echo allows participants to actively make rich records of daily events of their choosing. A record consists of a label and short description of the event, an emotional reaction to that event (ranging from '1' for a highly negative event, to '9' for a highly positive experience), and optionally added pictures, audio, or video (See Figure 1 for a screenshot of the recording interface). We have developed Echo iteratively over a period of 5 years and incorporated extensive feedback from long-term users. The current study used the third generation of the Echo prototype.

Echo was designed for simplicity, to increase compliance and encourage participants to make records, and when relevant, reflections. Thus we chose the event emotion rating to be a single judgment of "happiness" rather than a complex series of evaluations of multiple facets such as the emotion circumplex that requires training for reliable deployment [Ghallab 2008; Scherer 2005]. To ensure consistency between an individual's emotional ratings, participants in

the TMM groups created a personal emotional scale at the beginning of the study. This scale consisted of examples of personally experienced events corresponding to each rating on the emotional scale (e.g. a '9' might correspond to the birth of a baby or getting married, and a '1' to a partner's death or divorce). Participants were instructed to use this personal scale throughout the study when rating emotional reactions to event records and reflections. Using the scale should increase consistency of ratings when judging emotional reactions, as participants are able to compare their feelings about the current event against anchored events on their personal scale. During the intervention we confirmed on multiple occasions during follow-up calls that participants were indeed using this scale when making their ratings.

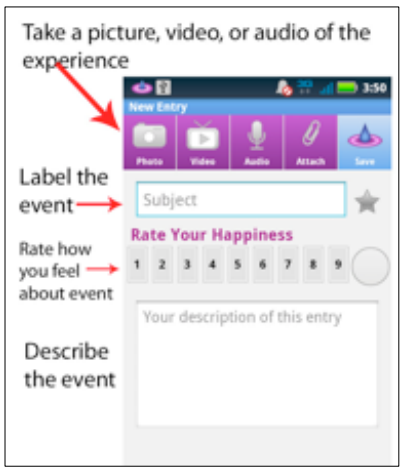


Fig. 1. The *recording* interface in Echo.

3.1.3. Procedure. We used a pretest-posttest design with 4 conditions (TM-recording, TM-reflecting, technology control, no-technology control), and the four validated well-being measures as dependent variables. Participants completed the 4 Pretest (Time 1) well-being surveys online (through https://surveymonkey.com), and the same 4 surveys at Posttest (Time 2) after 28 days. Following a previous pilot study, we chose a one-month intervention in order to allow reflections to occur after substantial time had elapsed from the initial recordings, but without extending the study to a point of high participant attrition. We discuss our follow-up long-term evaluation in Section 5.

Again based on pilots, participants from the TMM groups were asked to record a minimum of three times throughout each day and with recordings covering a broad range of emotionally experienced events. We instructed participants that "an event can be anything ranging from a social gathering, conversation, or lecture to just watching TV, getting good or bad news, having coffee with a friend etc." Actual recorded events ranged from highly positive (e.g. beginning a dream job), to very negative, (e.g. separation from a long-term partner).

To improve accuracy of recordings, participants were asked to record the event while they were experiencing it, or as close to the event as was practically

possible. Of course this was impractical in certain circumstances e.g. in certain social settings or when driving.

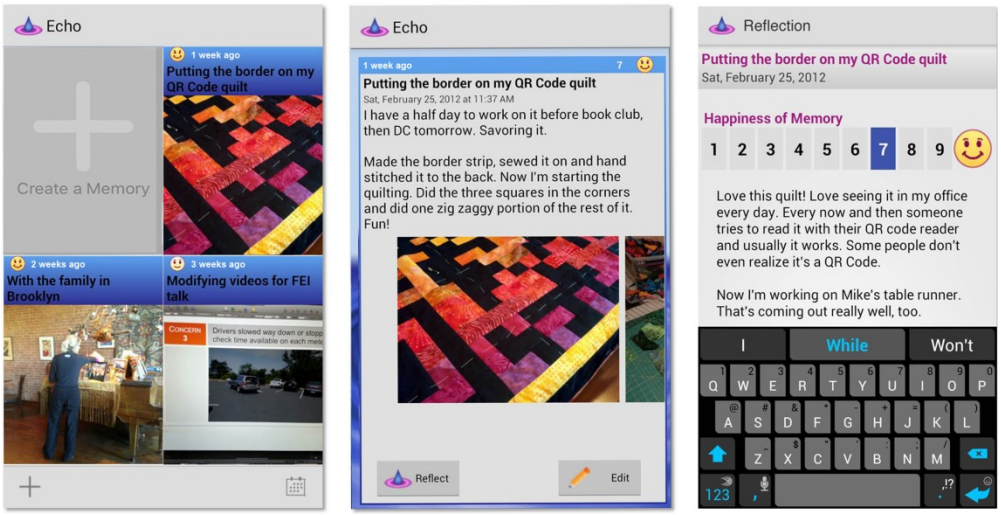
The *technology control* group used a modified version of Echo in which all TM-reflection capabilities were removed. Like the TM-recorders, they used Echo only to make recordings and had no reflection options. Additionally, unlike the TM-recorders and TM-reflectors, the technology control group version of Echo had no emotion rating options. Participants in the technology control group were instructed to record only emotionally neutral events and we did not want the presence of an emotion rating scale to prime participants to think about their emotions. It was challenging to identify emotionally neutral events for the technology control group to record, as few situations are devoid of affect. Following piloting, this group was asked to either record a neutral description of a city street they were on, or a neutral description of a visual pattern they saw. They were told not to record streets or patterns that were familiar to avoid nostalgic or emotional experiences.

All three Echo groups were trained how to use the system. Participants were not given any reminders to record, which allowed them to control which events they logged. The TM-reflection group received additional instructions and reminders to reflect. A TM-reflection involved participants first clicking on a specific previously recorded event from the Echo home screen (see Figure 2(a) for a screenshot of the home screen). This allowed participants to revisit the event description by reading what they wrote and how they felt at the time (see Figure 2(b) for a screenshot of the event description screen). Then, participants clicked the "reflect" button and re-evaluated the memory by writing a follow-up textual description stating how they now felt about that prior event, along with a new emotional rating of their current feelings about that event (see Figure 2(c) for a screenshot of the reflection screen). The reflection group received 3 reminders each day to reflect. There were two types of reminders:

(1) A system alert appearing in their notification bar (without making sound or vibrating so that participants were reminded to reflect in a non-intrusive way). Clicking on this alert automatically accessed the application at the event description screen (e.g. Figure 2(b)), bypassing the Echo home screen.

(2) Echo's home screen displayed three prior entries from different time periods for TM-reflection (e.g. one day ago, one week ago, two weeks ago etc.), randomly choosing one of the entries from each day and prioritizing older entries as time progressed (e.g. Figure 2(a)).

The TM-recording and technology control groups were unable to see prior recordings. To maintain compliance, all participants in the 3 Echo groups were phoned once a week to provide encouragement, answer questions, discuss any technical issues, confirm that they were using their personal scale for rating emotions and generally check-in. The no technology control group was not given any activities or technology to work with between pretest and posttest. At the end of the study, we asked participants who had created recordings or made reflections to share the logfile content of their posts after first browsing posts to remove any they didn't want to share. At the start of the study, to help encourage more honest, uninhibited recording and reflecting, we told participants that they would have control over which logfiles they chose to share at the end. All but 4 participants gave us access to their logs.



(a) Echo home screen (b) Event description screen (c) Reflection screen

Fig. 2. Screenshots of the Echo reflection process

4. RESULTS

4.1 Echo TMM improves well-being

Our first research question (RQ1) addressed whether Echo TMM improved or detracted from well-being by altering adaptive memory processes. To answer this question, we compared the scores of the combined TMM groups (TM-recording and TM-reflecting), with the scores of the control groups (technology and no-technology controls). We used a mixed-design multivariate analysis of variance (MANOVA) with one between factor (controls vs. TMM) and one within factor (Pretest vs. Posttest). The dependent variables were the four well-being scales (SHS, SWLS, PGWBI, and MAAS). Before deploying the MANOVA, each assumption for conducting MANOVA was assessed. None were violated: Box's M test was not significant (p=.61) indicating that the homogeneity of the variance/covariance matrix assumption was met. Levene's test was significant for all pretest and posttest scales indicating negligible multicollinearity.

The MANOVA results show that Echo TMM improved well-being; we found a difference between controls and TMM groups at Posttest but not at Pretest. Using Pillai's trace, a MANOVA revealed a significant interaction effect of time by group when we compared TMM groups with controls, V = .18, $F(4,59)$ = 3.24, p=.02, η_p^2=.18. Thus the combined TM-recording and TM-reflecting groups improved over time more than the combined controls. Univariate ANOVAs revealed that this interaction was driven by the Subjective Happiness scale, $F(1,62)$ = 5.97, p=.02, η_p^2=.09. See Table II for the means and standard deviations for the well-being measures by TMM vs controls at Pre and Posttest.

Table II. Means and standard deviations for four survey measures of well-being for TMM versus Controls at Pretest and Posttest showing that TMM groups improved overall well-being at Posttest compared with Controls. All scores are normalized to a 100 point scale.

		Combined TMM (n = 33)		Combined Control (n = 31)	
Well-being Survey		**Pretest**	**Posttest**	**Pretest**	**Posttest**
SHS	*Mean*	69.86	73.43	70.29	68.14
	Std Dev	16.14	14.86	16.00	14.29
SWLS	*Mean*	67.89	71.00	65.71	66.63
	Std Dev	16.97	16.00	16.77	17.03
PGWBI	*Mean*	62.70	66.67	64.69	65.22
	Std Dev	13.68	12.62	14.09	14.27
MAAS	*Mean*	68.33	67.50	63.67	66.67
	Std Dev	12.00	12.83	15.83	16.00

4.2 TM-recording and TM-reflection show equal well-being benefits

Our second research question (RQ2) examines differences between recording and reflection. To explore whether TM-reflection influenced well-being differently from TM-recording, we ran a separate MANOVA specifically comparing these two groups. Both TM-reflection and TM-recording groups improved well-being across time (V = .31, $F(4,28)$ = 3.09, p=.03, η_p^2=.31), but there were no differences between types of TMM. The interaction effect of time by group on the well-being measures was also not significant, V = .11, $F(4,28)$ = .90, p=.48. We had expected TM-reflectors to change more at Posttest, but the absence of an interaction shows this was not the case. This suggests that both TM-recording and TM-reflection engendered equivalent well-being benefits. Table III shows the means and standard deviations for the well-being measures by TMM group and time.

Table III. Means and standard deviations for four survey measures of well-being for TM-record versus TM-reflect at Pretest and Posttest showing no differences between TMM conditions. All scores are normalized to a 100 point scale.

		TM-Record (n = 17)		TM-Reflect (n = 16)	
Well-being Survey		**Pretest**	**Posttest**	**Pretest**	**Posttest**
SHS	*Mean*	68.71	73.14	71.00	73.86
	Std Dev	19.00	18.29	13.00	10.86

SWLS	*Mean*	70.09	74.80	65.54	66.97
	Std Dev	17.34	15.91	16.77	15.57
PGWBI	*Mean*	61.55	67.22	63.92	66.08
	Std Dev	15.75	14.09	11.47	11.29
MAAS	*Mean*	70.33	68.33	66.17	66.67
	Std Dev	13.17	14.00	10.50	12.00

4.3 Echo TMM shows the same adaptive biases as organic memory

To address our third research question (RQ3), we next examined the two TMM groups' daily emotion ratings and logfiles to see whether TMM data revealed the systematic memory biases that characterize organic memory. We first examine adaptivity biases and next evaluate how these biases affect well-being. We analyze combined TMM groups when they show common patterns, but present separate analyses when their behaviors differ.

Also, recall that participants could include pictures, audio, and video with the text of their recordings. Audio and video recordings were quite rare and too infrequent to run statistical analyses. Although pictures were quite common, we will see later that they did not affect our main results. Thus we focus on textual analyses of logfiles. Unless otherwise specified, reported analyses of survey data for the TM-reflection group include all 16 participants, but logfile and emotion rating analyses include 12 participants (4 chose not to share their logfiles). All the TM-recorders shared their logfiles. Degrees of freedom for statistical tests are adjusted accordingly. Also, unless otherwise stated, analyses are conducted using per user, rather than group averages to control for between-user variances.

4.3.1 Echo Shows Positivity of Affect Ratings and Reported Events

Recall that organic memory shows a bias towards reporting and remembering positive rather than negative events [Walker et al., 2003]. We found the same positivity bias in TMM participants' ratings of the events they recorded and reflected upon. The mean overall emotion rating for each participant for all TMM recordings and reflections combined was 5.81. A one sample t test showed that this is significantly different from a neutral '5' rating revealing a positivity bias, $t(28)=7.12$, $p<.001$, $d=1.32$.

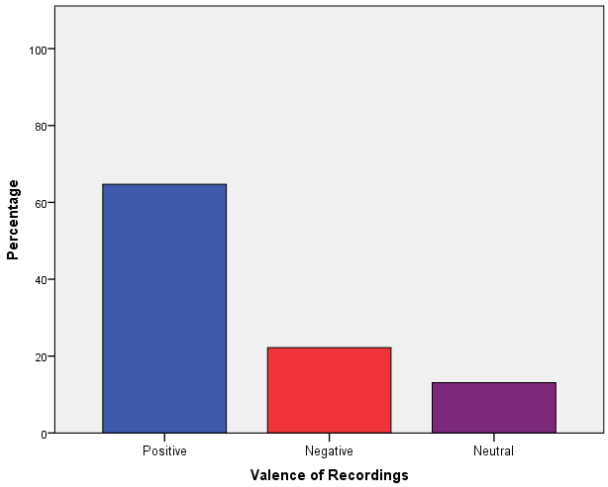


Fig. 3. Percentage of all recordings that are positive, negative, and neutral showing a strong bias to record positive rather than negative or neutral events

To explore this positivity bias further, we next examined the overall distribution of positive, negative and neutral event ratings for TM-recording and TM-reflection separately. Across both TMM groups, 64.7% of all recordings were positive, 22.2% were negative, and 13.1% were neutral (See Figure 3). This distribution is similar to the findings of Thompson et al. [1996] using unmediated recordings which were 59.5% positive, 25.8% negative, and 14.7% neutral. The picture was similar for reflections. Positive reflections also outnumbered negative reflections: 62.0% were positive, 20.6% were negative, and 17.4% were neutral (See Figure 4). These results are comparable to the Walker et al. [2003] findings of 50% positive, 25% negative, and 25% neutral for unmediated reflections.

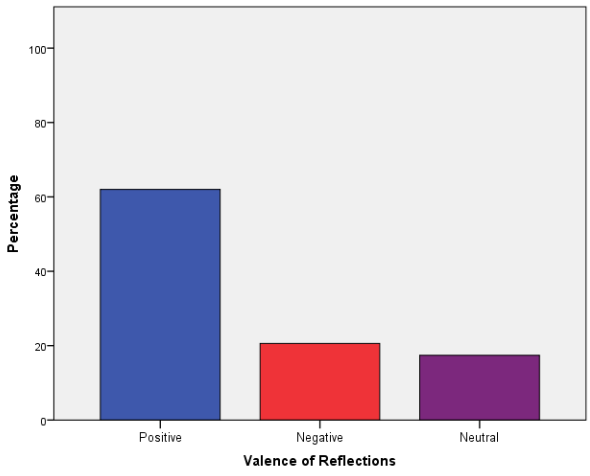


Fig. 4. Percentage of all reflections that are positive, negative, and neutral showing a strong bias to have positive rather than negative or neutral reflections

We next looked at the *content* of each TM-recording or TM-reflection by analyzing the words used in participant logfiles. We used LIWC [Pennebaker et al. 2007] to calculate emotional valence by examining the percentage of positive

(e.g., “happy”, “blessed”, “enjoy”) versus negative (e.g., “sad”, “disappointed”, “angry”) words within each recording or reflection. Again we found a positivity bias in the content of words that participants used overall. Each participant had a significantly higher percentage of positive words than negative across all posts, paired $t(28)=5.76$, $p<.001$, $d=1.41$ (Positive: M=5.81%, SD=2.73%, Negative: M=2.79%, SD=1.32%). See Figure 5. Again analyses refer to the 29 participants who shared their logfiles.

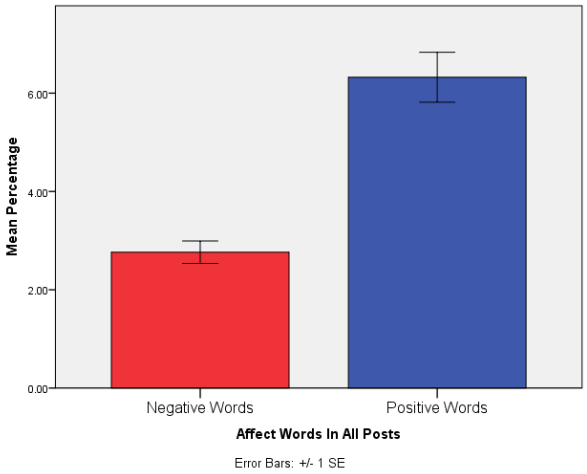


Fig. 5. Mean percentage of positive and negative emotion words used in all posts.

4.3.2 Fading Affect Bias and Rosy Retrospection

The fading affect bias in organic memory describes a tendency for the emotions associated with all event reflections to regress to the mean over time, but this regression happens a greater extent for negative compared with positive events [Walker et al., 2003]. To measure the fading affect bias, we examined how the TM-reflection group’s emotion ratings changed when they reflected on prior recordings. We didn’t examine this for TM-recorders as they didn’t revisit recordings.

We calculated the change in emotion ratings from initial recording to reflection for each event. We determined each person’s average change score, for both positive and negative emotion ratings, and found clear evidence of fading affect bias. There were no events that were rated 1, so we omitted the small number that were rated 9 so that the emotional intensity of ratings was balanced for both valences. We compared the average magnitude of change of negative emotion ratings (ratings of 2, 3 and 4) with the average magnitude of change for positive emotion ratings (6, 7 and 8), and ignored neutral ‘5’ events. This left us with 48 total emotion rating changes to compare. Change was measured relative to predicted affect fading, so that positive events were expected to become less positive and negative events less negative. We scored change positively when it conformed to the fading affect bias. Changes that didn’t conform were scored negatively. For example, an average emotion rating of 2 that became a 4 was a +2 change, and an 8 that became a 6 was also a +2 change, as both conformed to fading affect predictions. However, a 6 that became a 7 was a -1 change because it did not conform. Consistent with fading affect bias, we found that negative posts changed more than positive posts,

$t(46)=3.08$, $p=.003$, $d=.89$ (Negative: M=1.26, SD=.77, Positive: M=.62, SD=.67) Thus, negative recordings regressed to the mean more quickly than positive recordings over the 28 day intervention, showing that fading affect bias also occurs in Echo TMM. These results are shown in Figure 6.

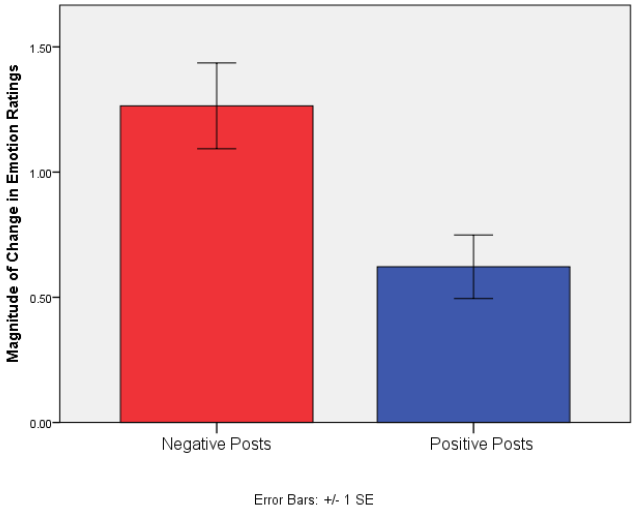


Fig. 6. Change in emotion ratings between recording and reflection, measured in absolute terms towards the mean. Greater change for negative compared with positive events support fading affect bias.

We also found evidence for adaptivity in the affective *content* of recordings compared with reflections. Using LIWC, for the 12 TM-reflectors for whom we had logfile data, a paired t-test revealed that these TM-reflectors had more positive emotion words in their reflections than their recordings, paired $t(11)=3.61$, $p=.004$, $d=.74$ (Record: 6.26%, Reflect: 8.83%, SD 2.70% and 4.09% respectively). This is evidence of rosy retrospection [Mitchell et al., 1997] since the content of posts became more positive over time. The following example shows how when revisiting initially negative evaluated recordings, TM-reflectors were able to discover positive aspects. The example shows the emergence of a redemption narrative about overcoming initially negative experiences:

TM-reflector1 Initial Recording: *Crazy amount of work: So my econ thing is due tomorrow! And the Monterey place asked me a bunch of technical questions because they're actually interested in me. And I still have the prototype for 80k due tomorrow and 162 and CE12 to take care of! Aaaaahhhhhhhh!*

TM-reflector1 Reflection 3 days later: *That shit was crazy, but* ***it was worth it****. I feel pretty accomplished and some people seem* ***impressed*** *with it.*

4.3.3 Prospective Editing: Adaptive Preparation for TM-reflection

One of our initial concerns was that technology would interfere with adaptive mechanisms for TM-reflectors by providing detailed records of information that would have been positively edited or forgotten by organic memory. But we have already reported in Section 4.1 that TM-reflectors experience well-being benefits from seeing detailed past records. So how do participants avoid discrepancies between what they record and what they remember unaided in order to accrue

well-being benefits? One possibility is that TM-reflectors *anticipate* reflection. They know that they will see their recordings again and so they strategically make reflection contents more positive. In contrast we should not expect TM-recorders to prospectively edit because they do not anticipate seeing their records again.

To test this, we compared differences in recordings between the TMM groups to determine whether reflectors were more likely than recorders to prospectively edit these. As expected, using LIWC, we found that TM-reflectors had more positive emotion words in their initial recordings than TM-recorders, $t(27)= -2.14$, $p=.04$, $d=.77$ (TM-reflect: 6.26%, TM-record: 4.60%). TM-reflectors may therefore anticipate that they will see their initial recordings later, and deliberately bias those recordings to include more positive words. Thus, the TM-reflection group may strategically craft initial recordings as a way of side-stepping potential side-effects of detailed TMM. We illustrate this possible explanation using examples of initial posts from TM-recorders and TM-reflectors.

Here is an example of a typical TM-recorder. He doesn't soften his language or explore positive aspects of his recording (rated a 4) presumably because he knows he will not see this recording again:

TM-recorder1: *That **dreaded** feeling: Having those feelings again of **dread** and **illness**. Is it because I am **afraid** of work or what? I do not like this feeling, I really really do not like this feeling!*

However, the following TM-reflector makes an initial recording that has the same emotional rating as the above example (also rated a 4), but in the detailed content of his initial post he finds an optimistic perspective to help resolve potential self-discrepancy:

TM-reflector2: *Broke up with [M].. again… I feel bad.. but **I know I made the right decision**. **Everything happens for a reason**… I don't think she'll ever let me back into her life I can only hope that she'll forgive me in her heart tho.*

4.4 Echo mechanisms for promoting well-being

4.4.1 Adaptivity and well-being

While we found clear evidence for adaptivity for Echo, we next explored whether this adaptivity promoted well-being. Do people who exhibit greater biases experience greater improvements in well-being? Various simple relationships between adaptivity and well-being were not found. We did not find a correlation between fading affect bias and well-being changes, nor did we find correlations between the positivity of content (rosy retrospection) and well-being.

However we did find other important relationships between adaptivity and well-being. Recall that the TM-reflection group engaged in prospective editing, making their initial recording more positive possibly anticipating future reviewing of that material. TM-reflectors who generated more positively rated recordings showed greater changes in the PGWBI well-being measure ($r(10)=.62$, $p=.03$). Subjective Happiness and MAAS also showed trending correlations with more positively rated recordings ($r(10)=.55$, $p=.06$ and $r(10)=.52$, $p=.08$).

We also found adaptive benefits for emotional distancing. Prior work has shown that high usage of personal pronouns ('I', 'me') is correlated with negative affect and in some cases, depression [Niederhoffer and Pennebaker 2002; Rude et al. 2004]. Use of personal pronouns in TM-reflections was negatively correlated with changes in Satisfaction with Life, $r(10)=-.59$, $p=.04$. As predicted, use of personal pronouns seemed to signal a failure to engage in adaptive distancing and led to decreases in well-being. Those who used fewer personal pronouns in their reflections showed greater improvements in well-being.

Also, we explored whether there were benefits to using richer media, e.g. adding images to written recordings. We therefore correlated change in well-being scales to the percentage of recordings that included a picture. Overall 53.66% of recordings included a picture. We did this for the 12 TM-reflectors and 17 TM-recorders who shared logfiles with us. Including more pictures while recording did not correlate with changes in any of the scales (SH: $r(27)=.12$, $p=.53$, SWL: $r(27)= -.25$, $p=.19$, PGWBI: $r(27)= -.04$, $p=.85$, MAAS: $r(27)=.06$, $p=.75$. Since only .62% of the records included video, and .97% included audio, we did not include these in the analysis.

4.4.2 *Autobiographical memory and well-being*

Finally we explored the other key functions of autobiographical memory, namely the directive and social. We found very different behaviors in TM-record and TM-reflect conditions and so we analyze these separately.

One key function of autobiographical memory is *directive,* where past experiences inform future behaviors. We used LIWC to identify words that are consistent with this function. These included auxiliary verbs ('should', 'can', 'will', 'ought') that are clearly associated with efforts to direct future behaviors. We were also interested in attempts to direct future behaviors based on current experience so we explored references to the present and future expressed through verb tense.

For TM-reflectors, increases in subjective happiness were positively correlated with specific characteristics of recordings including: a greater use of directive auxiliary verbs ('should', 'can', 'will', 'ought'), $r(10)=.59$, $p=.045$, along with more discussion of the present, $r(10)=.79$, p=.002, and the future, $r(10)=.60$, $p=.038$. This suggests that for TM-reflectors, it was adaptive to prescribe future lessons derived from present understanding (as indicated by this usage of tenses and auxiliary verbs). We saw many examples of TM-reflectors using their recordings to guide their future behavior, and then reflecting on their progress later:

TM-reflector3: *I **SHOULD** be studying, but I'm watching Grey's Anatomy on an illegal website instead, which is NOT a good thing :(*

TM-reflector3: 2 day later: *Yikes! I am trying to be good about only watching TV once I finish certain assignments. I hope I can keep it up! Maybe I can use it as a reward/incentive for finishing that assignment, haha. I'll have to see if that works or not, seeing how it hasn't really in the past :(*

A second function of autobiographical memory is *social,* where people use past personal experiences to promote interpersonal relations. Of course Echo

was not deployed in a social context, as participants recorded only for personal use. Nevertheless, we were still interested in whether referencing the social would improve well-being. We analyzed social words (such as he/she, talk about people and quoting others) and examined whether the presence of these social words corresponded with improved well-being. While social words did not correlate with well-being for the TM-reflection group, we did find benefits for social functions in the TM-recording group. Their increases in Subjective Happiness were positively correlated with use of he/she, $r(15)=.54$, $p=.026$, talk about people, $r(15)=.49$, $p=.048$, and using quotes, $r(15)=.48$, $p=.049$, suggesting that those who discussed relationships benefited more. Here we see an example of a TM-recorder benefiting from discussing positive outcomes of social interactions:

TM-recorder2: *Just had the best most **spiritually connected** conversation with [M] after sitting in sun in Union Square. **So grateful** that i can be so **grateful** with [M] about everything and **feel so understood**. Starting to just be me and do things despite what I think people will think.*

Other TM-recorders seemed to find benefits from being able to disclose their feelings and privately vent about people in their lives:

TM-recorder3: ***Can't stand him**. Or guys in general for that matter. I don't get it. Do they have to be so childish? **I don't understand men.** I don't know what they want. If I'm being honest, then I hurt their feelings. If I'm being nice, they take me for granted. If I try to be adaptive, they think I'm flaky. Maybe I'm just hard to get along with. Whatever. **There is nothing wrong with me. Fuck men.***

Participants were positive about this therapeutic aspect of Echo to assess and disclose about relationships, even going so far as to call it their "*personal venting machine*" and "*pocket therapist.*" One participant told us that *"it allowed me to talk about it a little bit I guess, sort of just get it out of my head."*

5. FOLLOWUP: LONGEVITY OF ECHO BENEFITS

Our fourth research question (RQ4) examined whether the benefits from our initial one-month intervention are maintained longer-term. Again we want to determine whether Echo TMM follows a similar pattern to organic memory. Pennebaker et al. [1997] found that benefits were greatest for reflection four months after their expressive writing intervention. We replicated that study design, comparing: (a) participants' initial pretest well-being, with (b) their well-being after a single month's usage and (c) their well-being four months after they had stopped using Echo. In order to replicate Pennebaker's study we tested only those participants who stopped using Echo following the one-month intervention.

5.1 Method

5.1.1. Participants. Participants from Experiment 1 were asked to complete the well-being surveys again to receive a $15 incentive. We provided an incentive because the follow-up was a post-hoc assessment that participants had not originally signed up for. Following Pennebaker's design, 6 participants were disqualified from taking the survey because they persisted with using Echo. Seventeen of the original 33 participants retook the survey for the follow-up, 8 of whom were female. We had a roughly even distribution of TM-recorders (n=9)

and TM-reflectors (n=8). None of the 17 participants reported using Echo after the one-month intervention.

5.1.2. Materials. We used the same well-being scales as in Experiment 1 with the addition of one question, about whether they had used Echo since the end of Experiment 1.

5.1.3. Procedure. The well-being measures were re-administered (Final Survey), four months after the end of Experiment 1 (Posttest). The researchers had no contact with the participants after the prior study finished. The Final Survey was compared to the Pretest and Postest to assess if participants' benefits remained four months after using Echo.

5.2 Results

Data were again analyzed using a mixed-design multivariate analysis of variance (MANOVA) with one between factor (TM-recording vs. TM-reflection group) and one within factor (Time 1:Pretest, Time 2:Posttest, Time 3:Final Survey). The dependent variables were the four well-being scales (SHS, SWLS, PGWBI, and MAAS). All of the assumptions for conducting MANOVA were assessed as detailed in Experiment 1, and none of the assumptions were found to be violated.

Table IV. Means and standard deviations for four survey measures of well-being for Combined TMM groups at Pretest, Posttest and Final Survey showing long term well-being benefits. All scores are normalized to a 100 point scale.

		Time (n = 17)		
Well-being Survey		Pretest	Posttest	Final Survey
SHS	*Mean*	74.86	79.00	78.71
	Std Dev	15.14	13.71	15.00
SWLS	*Mean*	72.43	75.46	76.14
	Std Dev	18.20	18.77	20.69
PGWBI	*Mean*	69.68	72.41	78.34
	Std Dev	10.40	10.58	7.93
MAAS	*Mean*	70.67	72.33	75.33
	Std Dev	10.00	9.67	11.50

The data are shown in Table IV. Using Pillai's trace, the interaction effect of time by group on the well-being measures was not significant, $V = .20$, $F(8,56) = .76$, $p=.64$. This shows that, as before, the two TMM groups received equivalent well-being benefits across the three time points. More importantly, however, the main effect for time (Pretest, Posttest, Final Survey) was significant for both groups combined, $V = .47$, $F(8,56) = 2.14$, $p=.046$, $\eta_p^2=.23$. Follow-up univariate ANOVAs found significant differences in means across time for the PGWBI scale, $F(2,30)=5.53$, $p=.009$, $\eta_p^2=.27$. Simple contrasts revealed that PGWBI increased from Time 2 to Time 3, $F(1,15)=5.72$, $p=.03$, $\eta_p^2=.28$, as well as across the entire study from Time 1 to Time 3, $F(1,15)=9.27$, $p=.008$, $\eta_p^2=.38$. Thus, both groups continued to receive well-being benefits for months after working with Echo. None of the other well-being scales showed significant differences over time.

Selection bias is a potential concern for all studies that experience participant dropout. We therefore compared the 17 participants who took the follow-up survey, with the 10 who did not (once again omitting the 6 who persisted with Echo), to assess if these groups were different. Echo affected both groups equally during the intervention. Participants who took the follow-up survey (at Time3) experienced well-being changes (from Time 1 to Time 2) that were equivalent to those who did not take the follow-up (p=.24). Also, there were no differences between these groups in number of recordings made (p=.62) or number of reflections (p=.69). Thus we don't see evidence of long-term effects arising from selection bias.

5.3 Discussion

While Echo increased well-being across our original one month study, our follow-up showed that these well-being benefits continued to develop even 4 months after working with Echo. The longevity of well-being benefits for Echo TMM seems to follow the same pattern as unmediated studies [Pennebaker et al. 1997]. Because we found increases in Subjective Happiness after one month, but long term increases in Psychological General Well-Being Index after 4 months, it may be that these scales are differentially sensitive across time. In other words, Subjective Happiness may be sensitive to short-term changes in well-being, whereas PGWBI benefits took longer to emerge. This might be explained by differences in the time scales of the probe questions. The PGWBI probes well-being over the past month. It might be more sensitive to our follow-up survey when well-being had stabilized, than the month long study when well-being benefits were still evolving. In contrast, the Subjective Happiness Scale probes well-being generally, without specifying a time interval which might lead participants to be anchored more closely to current happiness levels, making it more sensitive in our month long study.

6. GENERAL DISCUSSION

Despite the prevalence of TMM, we know little about how it affects organic memory processes and well-being. Contrary to some findings [Sas and Whittaker 2013], that suggest that TMM interferes with adaptive organic processes, we show that TMM can aid well-being compared with controls. The finding that Echo improved well-being for the TMM groups is also supported by the fact that 8 months later, 6 participants are continuing to use Echo. Strikingly, some of these benefits are still evolving four months after the

intervention. Our evaluation of Echo shows that TMM can also manifest exactly the same adaptive memory biases as organic memory, including overall positivity as evidenced in emotion ratings, content words, and ratio of positive to negative posts. Furthermore, the content of posts became more positive over time, suggesting rosy retrospection. Finally we found evidence of the fading affect bias as negative posts regressed to the mean faster than positive posts.

Both TM-recording and TM-reflection led to equivalent well-being benefits but seemingly through different mechanisms, although in both cases the results are consistent with organic autobiographical memory. TM-reflectors benefited from distancing reducing their self-focus in their reflections as evidenced by a drop in first person pronoun usage. Additionally, TM-reflectors took strategic advantage of the recording-reflecting procedure. In their recordings, they used present understanding to direct future behaviors as evidenced by auxiliary verb, present and future tense. On the other hand, TM-recorders discussed relationships, benefitting most from social functions. It's possible that the ephemeral nature of TM-recording lends itself to social venting. People may exploit TM-recording to savor and disclose about relationships, knowing that this private expression will never come back to haunt them. This contrasts with TM-reflectors who know that recordings will return. TM-reflectors' ability to manipulate future thinking provided a unique opportunity for behavioral guidance directed at their future selves, through future oriented actions and directive verbs. This preparation for reflection also led to some interesting behaviors, where TM-reflectors may have adjusted recordings to be more positive in anticipation that those recordings will be seen again.

We were concerned that the detailed records provided by Echo might interfere with adaptive organic memory biases. In unmediated contexts, such as Pennebaker's expressive writing, people rely on their organic memory of past experiences, which affords shifts in perspective, distancing and redemption. With TMM, however, the affordances are different. The rich window into their past provided by concrete reflections might have prevented TM-reflectors from changing their perspective, preventing them from editing the negative and enhancing the positive. However, our well-being data indicate that this was not the case. That rich window seems to only show users how they once felt, not how they should continue to feel. While recordings show some negative aspects of events that might have normally been organically edited, TM-reflectors still chose to focus on positive aspects, finding the bright side in their reflections. Organic rosy retrospection biases the recall of positive over negative details. However, in the TMM context this bias can express itself by consciously exploring positive details in reflections despite also being confronted with the negative. And although participants saw detailed records of how they felt at the time (with emotion ratings), we still observed the asymmetry of negative affect fading faster than positive affect. It appears that in TM-reflection participants are able to discern that they are not the person they once were, changing their stance on past recordings, rather than mirroring past indiscretions.

These consistencies between adaptive processes in Echo TMM and organic memory suggest that we don't need new theoretical accounts for this type of TMM, nor do we need to revamp organic theory. In the context of Echo, TMM and organic memory both exhibit adaptive biases that can benefit well-being. However, a deeper look at the mechanisms by which these benefits are

accomplished suggests differences. While organic memory automatically reduces self-discrepancies by selectively editing what is remembered and what is forgotten, TMM may encourage a strategic *manual* reduction of these discrepancies. Rather than subjecting themselves to reflections that highlight self-discrepancies, TM-reflectors may opt to prospectively edit their recordings to anticipate future viewings. Through benefit-finding and prospective editing, TM-reflectors manually resolve discrepancies so their reflections preserve a sense of positive self-continuity.

These active user strategies have interesting parallels to platforms like Facebook where users selectively present themselves positively to others [Gonzales and Hancock 2011]. Facebook TMM systems like On This Day have similar characteristics to Echo; they are active, selective, include diverse media, and have an option for written reflection (when sharing memories). In computer-mediated communication (CMC) and social media, technology often allows users greater opportunities to plan and edit messages than in face-to-face interactions. This provides a chance for selective self-presentation, with the goal of achieving positive impressions, likeability, and social favor [Walther 1996; Walther and Burgoon 1992]. Our work suggests a second benefit for positive self-presentation beyond social impression management. There may be *private* benefits for self-presentation by manually reducing self-discrepancies and prospectively editing posts that may be revisited on one's Facebook Timeline. This prospective editing complements prior work showing private benefits for *retrospective* curation of social media content (i.e. managing prior posts into a personal archive and life narrative) [Zhao and Lindley 2014; Zhao et al. 2013]. Thus while social factors influence Facebook content, there may also be private prospective and retrospective factors as well. Additionally, prospective editing may in part account for results such as Gonzales and Hancock's [2011] finding that revisiting past Facebook posts that had been positively edited increased self-esteem. This does not preclude benefits for more honest (negative) self-presentation on social media that provides opportunities for social support [Burke and Develin 2016; Kim and Lee 2011]. Concern about positive self-presentation has prompted the development of anonymous social platforms like Whisper and Chrends to encourage honest disclosure. Thus while honest self-presentation may have social benefits, positive self-presentation may have private self-enhancement benefits through TM-reflection. This is an intriguing possibility, updating the age-old advice to be "honest with yourself" to be "positive with yourself, and honest with others."

There are limitations to this work. It is based around a single system and results should be explored in different contexts with different classes of TMM systems. In future work we will also conduct qualitative analyses of our logfiles, checkins and interviews, such as those in [Isaacs et al. 2013]. These analyses might probe how and why participants felt that they obtained benefits from Echo, exploring whether benefits are obtained from better understanding of emotions, improved emotion regulation, or behavior change. Analyses will also explore our long-term users in more depth.

6.1 Therapeutic Implications

Reflection technologies could have significant therapeutic applications. In one survey study, participants said they were more receptive to computational approaches to mental health: 91% of respondents would prefer their therapy to

be computerized both to protect anonymity and to offer greater control over when and how they engaged in therapy [Graham et al. 2000]. This presents new research opportunities exploring whether our well-being findings from normal populations can be employed to non-normal populations (i.e. depression) with the same benefit. Our findings provide a framework of where to begin this new research. For example, TM-recording and TM-reflection might be useful for different therapeutic objectives. If the goal of the intervention is to help the patient understand their habits for health-related behavior change, the level of detail provided by TM-reflection might be a promising approach. If the goal is to help the patient work-through relationship issues, or open up about these relationships, TM-recording might be a preferable method. Lastly, if the objective is to raise the patient's general well-being, TM-recording might be most efficient since it doesn't require the extra effort of TM-reflection (which did not show additional well-being increases). This work is not without effort though. The patient must be willing to actively evaluate emotional events, since we've shown neutral TM-recording to be ineffective in our technology control. After a brief, month-long TM-recording intervention, some of the well-being benefits may continue to persist for at least four months. This can give therapists the opportunity to explore other interventions and work with the patient during a period of improved mental health.

Additionally, to understand possible therapeutic applications of TMM, future work must tease apart individual differences. Although we didn't address them in this study, underlying dispositions might interact with TM-reflection, increasing well-being in some and decreasing it in others. For instance, those disposed to rumination [Nolen-Hoeksema 1991; Nolen-Hoeksema et al. 2008], i.e. fixation on the negative, might find this to be unavoidable when revisiting detailed records of their past, even if those records have been prospectively edited to reduce the impact of self-discrepancies. In this study, well-being benefits suggest that rumination did not have a large maladaptive influence, but we should clarify this in future work and with non-normal populations.

6.2 Design Implications

Echo has many features of common TMM systems like active, selective recording of diverse media, and structured written reflection. Our findings speak to systems that share these same features, and provide design recommendations for those that don't. For example, our data suggest the importance of *active* recording for inducing well-being benefits. TM-recorders would not have been able to savor and disclose and TM-reflectors would not have been able to prospectively edit negative content if they had not had an opportunity to actively write about the event. Lifelogging systems like Sensecam or MyLifeBits that support automatic event capture may not promote well-being in the same way as active writing systems like Echo.

Furthermore, Echo provided *user-selected* recording of events. Systems that capture information comprehensively might overgenerate neutral or irrelevant information. Our control results show that recording and reflecting on such neutral events doesn't provide well-being benefits. Furthermore, like many TMM systems, including Pensieve [Cosley et al. 2009; Cosley et al. 2012; Peesapati et al. 2010], Echo allowed for reflection on a diversity of media sources

(though text was most common). Future research should explore whether our results change for different types of media, such as audio and video which were rarely captured in our study. Another related question is whether structured (written) reflection provides advantages over unstructured (mental) reflection in TMM. It is possible that users might not experience distancing or positivity biases without the written structuring of events for better perspective and understanding [Pennebaker et al. 1997; Smyth et al. 2001]

Also, new systems could be designed specifically to optimize adaptive mechanisms. There are many possibilities here. For example, prompts or structured templates might encourage users to use more positive wording (rosy retrospection), or elicit third person (distancing) in their reflections. For example Hollis et al. [2015] found benefits by presenting participants with structured prompts to encourage emotional reflection about the emotional consequences of future behaviors. And Peesapati et al., [2010] found that the emotional tone and length of structured prompts affected reflections. Following [Pennebaker and Chung 2011], users might also be encouraged to *explain* rather than simply state their feelings about past events. Along the same lines, recording technologies could suggest to users that they write about relationships, while reflective systems could prompt recordings directed at future behavior changes. Lastly, new systems might explore how to encourage users to record events that are emotionally salient, which our work indicates are more useful in improving well-being. This could be accomplished by giving phone alerts reminding users to record a salient positive or negative event each day. The benefits of TM-recording of emotionally salient events are suggested by the attrition rates of the technology control group. These participants reported finding recording neutral events to be very boring. The technology control group suffered a 64% attrition rate, whereas the TMM groups only had a 13% attrition rate. Emotionally valenced recording not only has a greater impact on well-being, but it is a more practical and enjoyable intervention than recording the mundane.

Finally, critiques of generic technologies such as lifelogging have argued that such general technology visions fail to move beyond statements about the need to 'remember everything' to specify exactly which aspects of memory they are supporting and why [Sellen and Whittaker 2010]. Critiques of related approaches such as quantified self offer similar arguments stating that quantified self approaches lack specific design information about how users might benefit from rich information about their pasts [Li et al. 2010]. Our results address both of these concerns. First they indicate important practical well-being benefits for systems that support active recording and reflection suggesting this is an important area for systematic exploration. There are many systems already in this design space such as Timehop, 1 Second Everyday, MorningPics, and Facebook's On This Day. With the notable exception of Pensieve [Cosley et al., 2012, Peesapati et al., 2010], ours is one of the first studies to show end user benefits for reflecting as well as to provide specific empirically motivated guidelines that specify exactly how such systems should be designed to allow users to learn from their pasts.

As TMM systems become more common, it is critical that we begin to better understand how technology influences memory and mental health. This paper answers fundamental questions about TM-recording, TM-reflecting, and well-being. Echo provided us with a new methodology to systematically measure

these processes, and suggests new system designs and guidelines that might improve well-being. This gives rise to new questions and exciting avenues for future research.

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