ReflectiveDiary: Fostering Human Memory through Activity Summaries Created from Implicit Data Collection

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ABSTRACT
Reflecting on previous activities can improve episodic memory and well-being. While manually recording activities and experiences is not always feasible, there is a range of mobile sensors that allow implicit recording of users' lives. In this work, we investigate how reflection on daily summaries created from implicitly collected data improves episodic memory. Therefore, we built *ReflectiveDiary*, an Android application that collects personal data streams to create daily summaries automatically. Over the course of 16 days, we collected data from 11 participants using information, such as calls, messages, and calendar data to help people recollect their activities. By comparing reflected with non-reflected days, we show that reflecting on implicitly collected data improves remembering of events and their surrounding details. We further present an analysis of different types of memory cues and their usefulness to inform the design of reflective tools that help people to improve their episodic memory.

CCS Concepts
•**Human-centered computing** → **User studies;** *Field studies;*

Author Keywords
Human memory; recognition; reflection; recording.

INTRODUCTION & BACKGROUND
Episodic memory refers to a personal experience recollected in the context of a particular time and place, and with reference to people participating in the experience [17]. Since episodic memory supports people having a feeling of continuity and a sense of self, it is an important factor for the perpetuation of the quality of life [13]. Nevertheless, as time passes, it gets difficult to remember past events [18]. *Reflecting* on past experiences can help to remember previously inaccessible episodic memories [1, 14].

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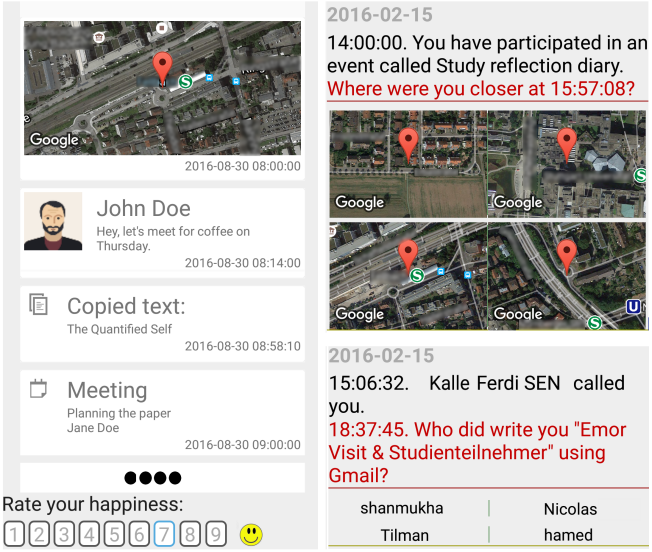

Figure 1. Reflecting with *ReflectiveDiary*, an Android app that creates automated summaries from implicitly collected data and invites users to reflect on past events. *Left*: Reflection screen. *Right*: Daily quizzes through which we assess the application's effect on memory.

Reflection is the activity of reviewing previous experiences and thinking about them to strengthen memory, gain a better understanding, and creating new insights [1]. Collecting personal information including habits, behaviors, and thoughts is the pre-stage of reflection. Tulving [20] proposed that retrieval of information from the episodic memory system occurs through a synergistic combination of information in the memory and provided retrieval *cue*, *i.e.*, a snippet of information that helps us remember. Previous work investigated tools and mechanisms that support human memory by collecting, processing and displaying retrieval cues [5]. Isaacs *et al.* [9] used a smartphone application that enables users to manually record daily experiences using pictures, audio and text, and reflect on them. Oleksik and Brown [16] investigated listening back sonic mementos to support episodic memory. However, explicitly collecting experiences and activities is challenging. People often do not have complete knowledge about themselves [21], and observing and finding patterns in their behaviors is difficult [15]. Furthermore, explicitly recording information requires time, motivation and interrupts everyday activities.

Lifelogging devices have become of interest to support episodic memory through reflection. Previous work, for example, used the *SenseCam*, a wearable camera that can automatically record pictures, to study how implicitly taken photos support memory recall [8, 19]. Commercial lifelogging devices, such as *Fitbit* [1], *Instant* [2] and *Narrative Clip* [3] can also assist users in exploring their data by enabling implicit recording of personal information. However, these tools either collect only a single type of data (*e.g.*, photos, time) or do not remind users to reflect on the data collected.

In this paper, we investigate the effect of reflection using implicitly gathered personal and contextual data on the episodic memory recognition. Therefore, we built an Android application called *ReflectiveDiary* that automatically collects personal data streams and contextual information including users' calls, messages, locations, and calendar data. Li *et al.* [14] suggest that reflection can be supported by implicitly and frequently collected data, and by providing different types of data presented together. Hence, *ReflectiveDiary* automatically creates daily summaries of the collected information and prompts users to reflect on them (see Figure 1). We conducted an in-the-wild study with 11 participants to investigate the utility of using implicitly collected data to create daily summaries on which users reflect on. Each participant used the smartphone application for 16 days.

This paper provides the following contributions:

1. *An in-the-wild assessment of implicit data sources* that shows their utility to support remembering.

2. A quantitative analysis showing that *reflection on implicitly collected data from mobile phones improves episodic memory*.

TECHNOLOGY-MEDIATED REFLECTION

Technology-mediated reflection (TMR) is a practice in which applications or websites assist users in collecting data and encourage them to revisit the recordings later. Previous work showed a positive psychological effect of TMR on well-being and memory [9]. Related work also investigated using reflection to improve physical health. The presented technologies visualize the recorded data to encourage people to be more mindful of their diet [6] or physical activity [3]. Gouveia and Karapanos [7] presented *Footprint Tracker*, a tool that allows the review of lifelogs to support memory and reflection of daily activities and experiences. Choe *et al.* [2] developed *SleepTight*, an Android application which helps users to record and reflect on their sleep behavior. Kim *et al.* [11] presented *TimeAware*, a tool that allows people to capture and reflect on how they use their personal computer. Overall, previous work either required manual data collection or conducted studies in controlled environments. It remains unclear, however, if human memory can be supported through implicitly collected data that users reflect on in-the-wild.

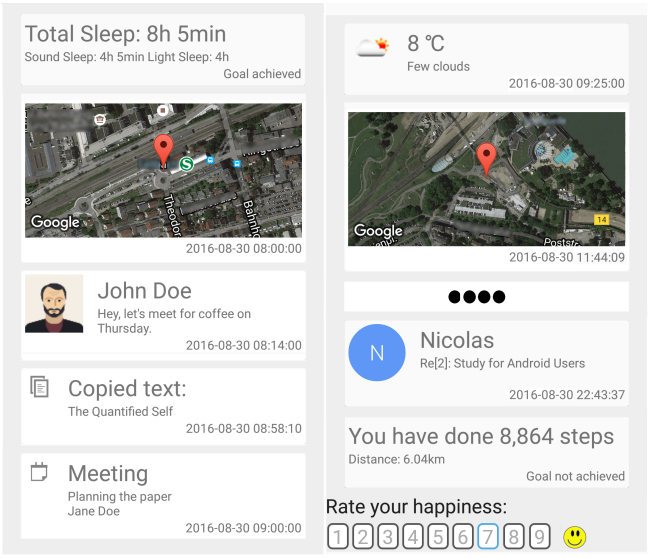

Figure 2. Reflection screen is showing presentations of implicitly recorded sleep, location, communication, clipboard, calendar event, weather and movement data.

THE REFLECTIVEDIARY APPLICATION

To investigate the effect of reflection on episodic memory recognition using implicitly recorded information, we developed the Android application *ReflectiveDiary*. It invites users to reflect on automatically created daily summaries of their personal information. The app uses notifications to prompt users to reflect on the data collected from the previous day.

ReflectiveDiary uses Android's application programming interfaces to retrieve different types of personal and contextual information. The app automatically records the user's sleep and movement behavior, visited places, weather information, communication data, calendar events, and smartphone clipboard data. Table 1 shows these data types along with the APIs used to collect the data and time interval, in which these APIs are accessed. All recorded data are stored on the users' devices.

ReflectiveDiary fetches communication data from 157 different communication applications by collecting notifications created by them. The selected 157 applications were the most common email client, messaging and social network applications used in the country of origin. The sources for communication data are incoming and outgoing phone calls, the Android's SMS application, social network applications as well as messaging and email clients. Notifications are filtered by package name and recorded only if they are originated from one of the 157 apps.

The sleep and movement data are collected using *Jawbone UP2* fitness trackers. The *Jawbone UP2* is a wristband that allows automatically tracking of user's movement and sleep behavior. Once a day the *ReflectiveDiary* application accesses the Jawbone UP API to record the tracked movement and sleep data.

[1] https://www.fitbit.com
[2] https://instantapp.today
[3] http://getnarrative.com

Data type	Used API	Access interval
Calendar	Android Calendar Provider API	once a day
Call	Android TelephonyManager API	permanently
Clipboard	Android ClipboardManager API	permanently
Location	Google Play Services Location APIs	every 20 minutes
Movement	Jawbone UP API	once a day
Notification	Android NotificationListenerService API	permanently
Sleep	Jawbone UP API	once a day
Weather	OpenWeatherMap API	every 2 hours

Table 1. APIs accessed and corresponding time intervals for the data collection. *ReflectiveDiary* collects data using APIs provided by Android, OpenWeatherMap and Jawbone UP.

ReflectiveDiary accesses the user's location every 20 minutes and stores it if the current place is at least 100 meters away from the previously recorded location. It further retrieves weather data every two hours from the *OpenWeatherMap API* [4] and stores it if the temperature differs by at least 3° C from the previously recorded temperature or if the weather description has changed.

Every recorded item contains multiple memory cues. Communication data, for example, contains three different cues: the sender, the receiving time, and its content. *ReflectiveDiary* implicitly records the data and creates a summary of the collected memory cues as shown in Figure 2. Since episodic memory preserves temporal order [4] *ReflectiveDiary* presents the summary in the order of the recordings' occurrences (see Figure 2).

We used simple representations for all collected data types to make it easier for users to understand their type. Notifications and calls are displayed with an icon, the name of a person or an application and a text containing either the content of the message received or information about callee or caller. Location data is displayed as a map with a marker showing the position of the user. Weather data is displayed with a weather description, corresponding weather icon, and temperature. Calendar events are presented by the calendar icon, title and starting time of the event. Moreover, event description and a list of participants are also displayed, if they are available. The clipboard data is shown by an icon and the copied text. To illustrate sleep behavior, a user's total sleep duration, the duration of light and sound sleep and if the user's sleep goal was achieved are shown. Similarly, to present a user's movement behavior the number of steps taken and if the user's daily movement goal was achieved are displayed.

By automatically creating quizzes using the data recorded, *ReflectiveDiary* allows memory studies on reflection to be conducted in-the-wild. The application creates a multiple-choice quiz for each day using the data collected during the day. The number of quiz questions depends on the amount of data recorded on a respective day. *ReflectiveDiary* provides a *cue* for each generated quiz question. The cues and questions are created using different data types (see Table 1) collected on the same day. For example, the application can provide information about a calendar event as the cue and ask the participant to select the location he or she was situated at the particular time on the same day (see Figure 3). Another example could be showing a call as a cue and asking the name

[4] http://openweathermap.org/api

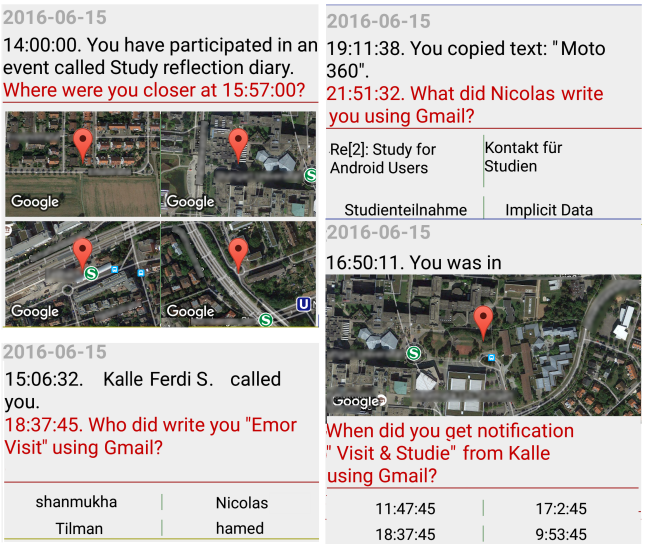

Figure 3. Quiz screen showing four cue and question pairs.

of the person sent the message using the particular application and at the specific time. Cues presented with one quiz question are not the subject of another question in the same quiz.

ReflectiveDiary generates four types of questions: it asks about people (*Who*), places (*Where*), time (*When*) and contextual information (*What*). For example, the application can use a notification as communication data to create a question such as *10:30:00. Who did write you "I'll be in 5 minutes there" using WhatsApp?* Furthermore, *ReflectiveDiary* can use the same communication data to generate questions asking the content of the notification or time the notification was received. The application creates questions about a place if the used data is either from the type of location or calendar event. For sleep and movement behavior data, the application asks if the sleep or movement goal was achieved. Sleep and movement behavior data belongs to a whole day, therefore, *ReflectiveDiary* can use all but sleep and movement behavior data to generate questions asking for the time. The application can also use communication and calendar event data to create questions asking about people. Except for call and location data *ReflectiveDiary* can create questions asking contextual information. The contextual information can include occurrences such as weather changes, achievement of sleep and movement goals, the content of the received messages, the copied texts and the name of calendar events.

The application provides four possible answers to each question except for quizzes asking for movement or sleep data. In these cases, the participant can answer the achievement of sleep or movement goal with *Yes* or *No*. Choices for location questions are displayed as maps with a marker indicating a possible location of the user at the certain time. For quizzes asking about time, people or contextual information the application generates choices in the form of text. *ReflectiveDiary* creates choices using the collected data as well and thereby applies several rules. First, all created choices have to be unique. For location questions, the application creates choices so that there is at least 100 meters distance among locations. If the application does not have enough recorded location data

to create choices, it will generate random locations that are not far from, but at least 100 meters away from the participant's already collected visited places. Second, the application creates choices using the same data type as the question was generated. For example, *ReflectiveDiary* generates choices for the question "13:30:00. What did John Doe write you using WhatsApp?" from the collected WhatsApp messages that the participant has already received. All choices but one are either not from the same sender or recorded on the different day than the question belongs. The application creates choices using the entries collected from the same data type. However, if there is not enough recorded data, choices will be generated using alternative sources. For instance, if the application created a question using a captured WhatsApp message, and there are not enough, at least three more recorded WhatsApp messages to create wrong answers, *ReflectiveDiary* creates choices using SMS messages or messages collected from other messaging applications.

IN-THE-WILD STUDY

We conducted an in-the-wild study to investigate the effect of reflection using implicitly collected data on the episodic memory. Further, we compared the recognition of reflected and non-reflected data that has been implicitly recorded. We hypothesized that

H1: implicitly collected data can be used as an effective memory cue, and

H2: reflection on automatically created daily summaries will lead to higher recognition.

Method

We used a repeated-measures design with reflection being the independent variable resulting in two conditions: 1) recognition of data that participants reflected on (*reflected data*) and 2) recognition of non-reflected data (*non-reflected data*). To make it possible to conduct the study in-the-wild and to assess how well participants recognize events, we asked them to complete a daily quiz that we provided in *ReflectiveDiary* (see Figure 3). As dependent variables, we measured quiz results. Furthermore, we collected the results of questionnaires that were integrated into the application asking how each collected data type is useful for reflection to recognize previous activities.

Procedure

After explaining the purpose of the study, we asked participants to sign a consent form and recorded demographic data. We then handed participants a Jawbone UP2 fitness tracker, described how to use it and explained how to synchronize its data with their smartphone and set daily sleep and movement goals. Afterward, we installed *ReflectiveDiary* on their Android smartphone and introduced its usage. We explained to our participants that the application stores the private data only on their smartphones.

The study had two parts taking eight days each. During the first part, *ReflectiveDairy* collected data. Every second day, it prompted participants using the Android's notification feature to reflect on the data recorded on the previous day. In reflection

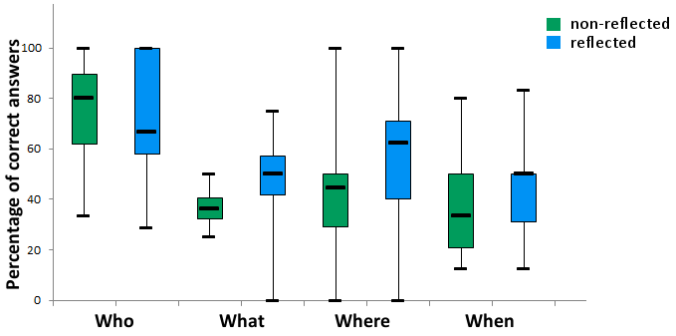

Figure 4. Average score of quiz results for four different type of questions asking a person (*Who*), contextual information (*What*), location (*Where*) and time (*When*).

days, the participants could reflect on their recorded data only once and after being prompted. To ensure that participants were always reflecting on the data after being prompted, we added a feature to the application that participants interact with it after reflection. Namely, we put a happiness scale from one (low) to nine (high) at the end of the reflection list (see Figure 1). The application triggered Android notification every day approximately at 10 pm to invite participants to use it.

In the second part of the study, the application notified participants once a day approximately at 10 pm to take a quiz. Quiz questions were based on the information collected eight days before. After taking a quiz, participants reviewed the data of the quizzed day again and rated the usefulness of each data type to remember the day. For the rating, we used 7-point Likert items. After the second part of the study, we conducted a semi-structural interview with each participant. During the interviews, we asked them to recount memory cues that helped them a lot and less to remember their days, if reflection on their previous days affected their mood, and if the application enabled them to become aware of their phone usage and personal behaviors. Furthermore, they were encouraged to give examples of events that were remembered after reflection. Participants were also given the opportunity to provide improvements for the application and additional feedback.

Participants

We recruited 11 participants (9 males, 2 females) through our university mailing list. Their average age was 26 years (SD= 3.69), and most had a background in IT or were university students. No participant owned any digital lifelogging devices. Two participants were keeping diaries, and one used a smartphone application to keep a diary. Participants were remunerated with 20EUR for taking part in the study.

RESULTS

The application recorded on average 12.4 calls, 574.6 SMS messages and notifications for messaging, email client and social network applications, 4.4 calendar events, 9.1 clipboard data, 49.1 locations, 37.1 weather, 16 movement and sleep events per participant. Each participant answered on average 75.3 questions. The average happiness rating was positive (M= 6.44, SD= 1.37).

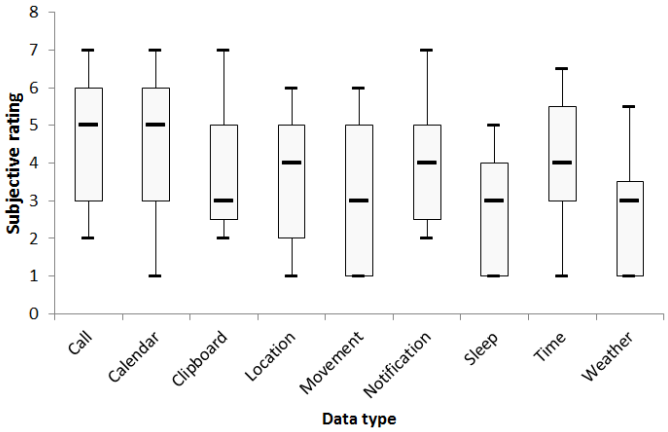

Figure 5. Subjective ratings of collected data types (cues).

Quantitative Measures

We used a repeated measures ANOVA to test if reflection and type of question had a significant effect on the percentage of correct answers (see Figure 4). It showed a main significant effect of reflections on the percentage of correct answers ($F_{1,10} = 7.322, p = 0.022, \eta_p^2 = 0.423$). Participants answered more questions about reflected days correctly (M= 55.43, SD= 3.59) compared to questions about non-reflected days (M= 47.74, SD= 2.67). A Greenhouse-Geisser corrected ANOVA also revealed a main significant effect of type of question on the percentage of correct answers ($F_{2.63,26.26} = 7.515, p = 0.001$). We found no significant interaction effect ($F_{2.13,21.29} = 0.67, p = 0.531$). Bonferroni corrected post hoc tests showed that participants provided significantly more correct answers for questions about persons (*Who*, M= 73.44, SD= 5.43) compared to questions about time (*When*, M= 40.83, SD= 5.05, $p = .009$) and questions about contextual information (*What*, M= 42.18, SD= 3.47, $p = .008$). No other differences are statistically significant (all $p > .05$). Participants answered M= 49.88, SD= 7.49 of the questions about locations (*Where*) correctly.

Figure 5 shows the subjective rating of the nine data types. Participants assessed how each data type was useful to remember a specific day on a scale from one (low) to seven (high). The highest rating was received by *call* and *calendar* data types, followed by *notification*, *time* and *location* data types. We used a Friedman test to find if the type of data had a significant effect on the subjective rating. The difference was statistically significant, $\chi^2(2) = 17.183$, $p = 0.028$. We conducted a post-hoc analysis using Wilcoxon signed-rank test with a Bonferroni correction and found a statistically significant difference between subjective rating for *call* and *weather* entry types, $Z = -2.820$, $p = 0.005$.

Qualitative Feedback

At the end of the study, we conducted semi-structured interviews to collect subjective feedback. All participants confirmed the benefit of being reminded to reflect on their previous daily activities in a single screen that makes it easy to see the relationship between them. They also commended the advantages of implicit data collection which helped them to save time: *"I love to see my day. The app was automatically logging, and I could travel back by tracking my day... I did not need to write everything by hand."* Six participants stated that reflecting on the collected data gave them a feeling of accomplishment: *"This app helped me to be mindful. It showed me what I have done. It also helped me to plan the next day."*

The recorded location information was interesting for participants when it was different from the location of their home or workplace. Confirming prior work [10], reflection on location information helped users to reconstruct a memory. One participant explained: *"I saw the location information, and it helped me to remember that I visited my parents. I had forgotten about that."* Furthermore, reflection on daily summaries assisted participants in remembering further activities or experiences, which were not recorded: *"While reflecting on a daily summary after taking a quiz (reflecting on activities recorded eight days before) I recalled our trip on that day and the fun I had. It brought some memories back."*

Nine participants reported that reflection affected their mood. They stated that this occurred mostly after reflecting on received messages. Two of these participants said that reflection affected only their temporary mood. Reflection on implicitly collected information also helped participants to gain new personal insights. Three participants stated that by using *ReflectiveDiary* they became more aware of their phone usage: they were surprised about the number of messages they received a day. The application helped five participants to be aware of their sleep and movement behaviors.

All participants reported that communication data, especially received messages were useful memory cues. While reflecting they could remember not only people they communicated to but also the context of the communication. However, five participants said that not all received messages are important. Therefore, they wanted a possibility to decide the messages manually that the applications records. Since the participants made and received calls rarely, it was easy for them to remember information about calls.

The participants also suggested improvements to the application. The application presented all recorded entries for a day in their temporal order. When *ReflectiveDiary* recorded too many entries for a day, it was difficult to follow each of them. Several participants noticed this limitation, and they proposed a feature that enables the grouping of entries by their data types. Two participants further wanted to be able to see weekly and monthly views of their recorded activities.

DISCUSSION AND LIMITATION

The percentage of correct answers for reflected recordings was 16.1% higher than for non-reflected recordings. Therefore, reflecting on implicit collected data improved recognition of previous activities and experiences, which confirms our hypothesis **H2**. Participant responses during the interviews showed that reflection on automatically created daily summaries also enhanced recall of surrounding events that were not recorded by the application. Confirming previous work [12], our results show that the participants remembered people better than places, time or other contextual information. The application extracted information about people from

calls, calendar events, and incoming messages. Since calls and calendar events were rare, and participants could match messages to its sender, the recognition of people was higher than of others. Our study showed that participants preferred reflecting on calls, calendar events, notifications, time and location information, all of which can be implicitly collected, thereby confirming **H1**.

Our results suggest a number of design implications: Reflection on implicitly collected data is feasible. Hence, reflection tools can be partly or entirely based on automatically recorded data. Further, customization of the reflections should be enabled, since our study participants wanted to be able to sort and group entries based on event type, as well as decide which incoming messages to record. Participants further expressed that incoming messages helped them to remember previous days and sometimes resulted in a temporary mood change. In future work, these message and notification characteristics need to be investigated. Furthermore, we need to investigate whether improvements on recognition can be maintained long-term as well as whether reflection on implicitly created daily summaries will result in behavior change. Limitations of the conducted study are that only 11 participants took part in the study, and they were mostly young people that usually need fewer memory aids. For future evaluation, we need a more diverse set of participants. However, we assume that *ReflectiveDiary* is also useful for older adults, and this should be investigated in future work. *ReflectiveDiary* collected data only from smartphones and Jawbone UP2 fitness trackers. We envision further lifelog devices soon to become available, more robust and context-aware, which will allow recording more versatile and accurate data for reflection.

CONCLUSION

In this paper, we investigated how reflection on implicitly collected data can be used to improve episodic memory recognition. As this does not require manual recording of events, it does not disrupt users' activities. Therefore, we developed *ReflectiveDiary*, an application that automatically records personal and contextual information to create daily summaries for reflection. Through an in-the-wild study, we show that reflection on implicitly recorded data improves memory recognition. Furthermore, we elicited appropriate memory cues that support recognition to inform the design of episodic memory tools. With the proliferation of lifelogging devices and increasingly sophisticated context-sensing, implicit data generation increases and allows for the creation of more comprehensive daily summaries to foster episodic memory.

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