DailyExp : A Tool for Collecting Cognitive Performance and Physiological Data in Daily Life with Engaging Behavioral Design

Xianyin Hu
Graduated School of Frontier Sciences
The University of Tokyo
Chiba, Japan
Email: shenyin@s.h.k.u-tokyo.ac.jp

Yuki Ban
Graduated School of Frontier Sciences
The University of Tokyo
Chiba, Japan
Email: ban@edu.k.u-tokyo.ac.jp

Shin'ichi Warisawa
Graduated School of Frontier Sciences
The University of Tokyo
Chiba, Japan
Email: warisawa@edu.k.u-tokyo.ac.jp

***Abstract*—Experimental designs in cognitive science that rely on laboratory-based settings are not only costly and time-consuming but also fail to capture individuals' cognitive states as they naturally fluctuate over time in daily life. We presented a practical tool implemented as a smartphone application that aims to conveniently collect cognitive performance data in daily life settings. This application is accessible from major mobile platforms (iOS, Android), tied with a Fitbit account to collect physiological data at the same time. We employed engaging behavioral design to overcome several problems facing experimenting in wild, intended to improve data quality as well as data collection efficiency.**

***Keywords*—data collecting tool; engaging design; physiological data; cognitive performance;**

I. Introduction

Cognitive science has long focused on understanding the mechanism of human cognition at an aggregate level, but individual differences have become an increasingly important topic. Recently, researchers have adopted a perspective that views individuals' cognitive states as a dynamic system that fluctuate. It is also suggested that the fluctuation in cognition is related to fluctuation in physiology from an embodied cognition perspective [1]. In this study, we focused on investigating individual differences and intra-individual variations in well-studied cognitive mechanisms. We addressed that the experiment should be conducted in a well-designed way but in a real-life environment rather than in a laboratory, since the latter is not practical to accumulate a large amount of data that covers both the population variation and intrapersonal variations. Furthermore, laboratory environments may induce high arousal levels that shift individuals' cognitive and physiological states due to nervousness and unfamiliar environment. To address the above issues, we advocate an approach involving real-life big data accumulation of cognitive performance and physiological signals. Previous attempts have been made to adopt smartphones and smartwatches as assessment tools, including iVitality [2], DelApp [3], Cognition Kit [4] and UbiCAT [5]. These studies showed a good correspondence between data obtained from the mobile-based tools and that from the laboratory, indicating that mobile-based tools are feasible for evaluating cognitive function. However, challenges such as a lack of user engagement throughout a prolonged experiment still exist in an experiment conducted in the wild that depends largely on participants' voluntary behaviors.

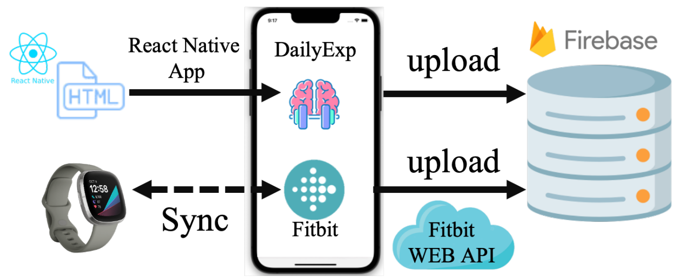

Fig. 1. Overview of the system design.

This study provided a practical implementation of a tool for data collection of both cognitive performance, as well as physiological data in daily life settings with engaging behavioral design. An alpha version of the smartphone application DailyExp is readily available that can conduct various classical paradigms in cognitive science. The application was linked with a widely used commercial smartwatch (Fitbit) to collect physiological data at the same time. This application is accessible from major mobile platforms (iOS and Android). We employed multiple practices of engaging behavioral designs to overcome several challenges facing experimenting in the wild.

The paper is structured as follows: In Section 2, we provide a detailed description of the implementation that covers the technical aspects to develop the tool. In Section 3, we evaluated the system through a one-month user study involving ten participants. In Section 4, we discussed future directions and potential enhancements to further improve the system. We also discuss its potential applications in different domains of cognitive science, showcasing its versatility. In Section 5 we present a brief summary that highlights the achievements of this paper.

II. Implementation

A. Implementation Details

Fig 1 showed the overview of the system design. The mobile client of DailyExp was developed using React Native, a web-based open-source framework for mobile application development. React Native was chosen to ensure compatibility across multiple platforms for iOS and Android devices. For the server side, Firebase's data storage service was utilized to store data, including users' daily summary data, cognitive

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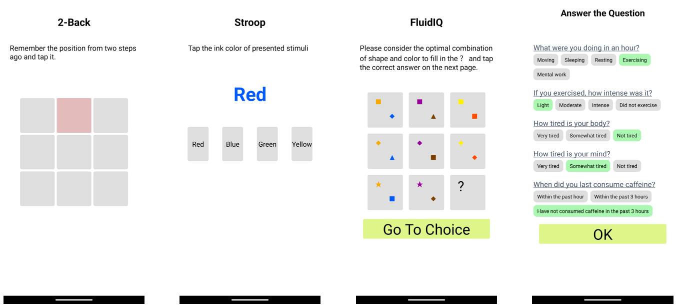
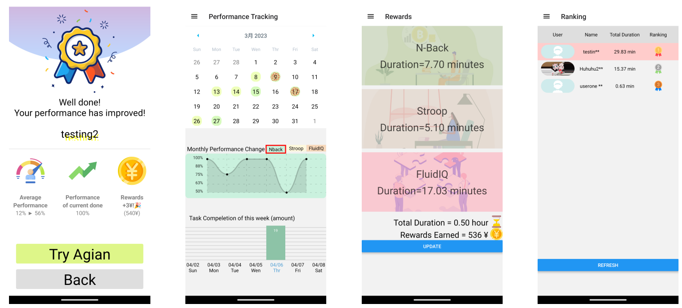


(a) (b) (c) (d)

Fig. 2. Screenshots of DailyExp. (a) The 2-back task. (b) The Stroop task. (c) The FluidIQ task. (d) The post-task questionnaire.



(a) (b) (c) (d)

Fig. 3. Screenshots of DailyExp. (a) The encouragement view. (b) The performance tracking view. (c) The rewards view. (d) The ranking view.

performance data for various tasks, and physiological data grabbed from the Fitbit server using Fitbit web API.

B. Cognitive Tasks

In the alpha version of DailyExp, three well-established cognitive tasks were administrated to study working memory (N-back), attention and executive function (Stroop), and fluid intelligence (FluidIQ or Raven's Progressive Matrices) as shown in Fig 2. (a)-(c). These tasks were selected due to their robustness and potential to have individual differences and intrapersonal fluctuations in the corresponding cognitive ability to be evaluated. Performance data with the timestamp, problem context, users' response, and reaction time will be recorded and uploaded to the Firebase server.

C. Dealing with Unexpected User Behavior

An issue facing the experiment that relies on users' voluntary behavior is that users do not always behave in a desired manner. Predictable behaviors include forgetting to wear the smartwatch, responding randomly without involving the target cognitive process to be assessed, and an improper understanding of the procedures for the tasks. These behaviors will lead to a lack of data and noisy meaningless data. To address these issues, our application implemented several features to reduce unexpected behaviors. Firstly, we provided reminders of wearing the smartwatch before the start of any task. Secondly, practice mode with feedback will help users familiarize themselves with the task procedure. Moreover, user performance is recorded to monitor if it falls below a preset threshold. Users will be notified of invalid conduction due to their suboptimal performance. Another concern facing an experiment in wild is that it is difficult to control factors that are not the target of interest, such as physical activities and caffeine intake, which give a great influence on the cognitive and physiological state. As a solution, we provide a self-report questionnaire (Fig 2. (d)) after completing the task. This enables data to be nicely categorized and analyzed afterward.

D. Engaging Behavioral Design

We leveraged multiple practices of engaging behavioral design aiming to improve the efficiency of data collection, which is largely determined by user engagement. Fig 3. (a) showed the encouragement view that popped up immediately after each task conduction, notifying users about how well they performed this time compared to the past. We expect this action-reward link leads to the habitation of voluntary conduction of cognitive tasks. Fig 3. (b) showed a performance tracking view from a long-term perspective. The calendar and line chart displayed the monthly task executions and performance fluctuations, while the bar chart showed the task executions for the current week. This feature took advantage of human's tendency to make more effort towards specific goals when they feel in control of their actions. We expect this feature to satisfy users' desire for autonomy and increase intrinsic motivation. Fig 3. (c) illustrated the monetary rewards earned, along with detailed information, such as the amount of time spent on each task and the corresponding rewards. In addition to providing an external motivation, this feature also promotes transparency of the experiment and is expected to enhance the psychological safety of participants. Finally, a ranking view (Fig 3. (d)) was implemented as a social motivation leveraging the competitive mindset by allowing users to see others' task executions.

III. Evaluation

To evaluate DailyExp, we recruited 10 students (M=6, F=4, aged 21-27) to download the alpha version and used it for one month. A monetary reward of 100 Japanese yen was given for each valid task completion. Participants were requested to fill out a brief questionnaire after the study, which gathered information regarding their level of busyness during the experiment period and identify the specific aspects of DailyExp that motivated their engagement.

Throughout the study, we obtained a total of 833 rounds of cognitive performance data, concurrently capturing corresponding physiological data. Fig 4. (a) illustrated the distribution of task completions, with 322 rounds for the FluidIQ task, 290 rounds for the Stroop task, and 235 rounds for the N-back task. A summary of user engagement was illustrated in Fig 5. Six out of the ten users (user 2, 3, 7, 8, 9, and 10) actively engaged with DailyExp, incorporating it into their daily lives throughout the study period for more than ten days. Notably,

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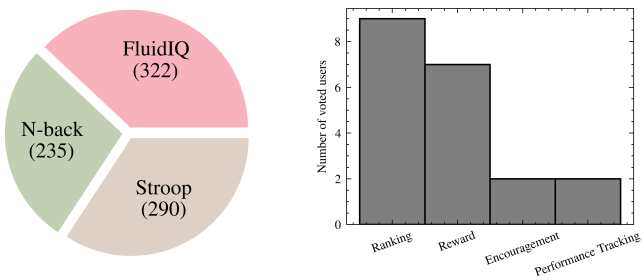

(a) (b)

Fig. 4. (a) The total number of task completions for the three cognitive tasks collected from 10 users over a month. (b) The count of users who voted for screens that motivated their engagement. Users were allowed to make multiple choices.

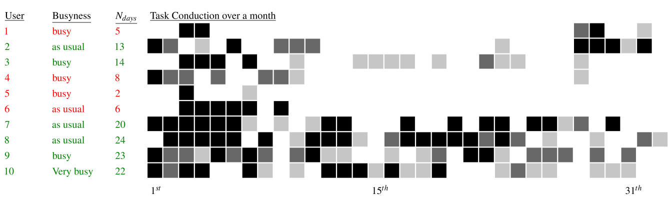

Fig. 5. User's busyness and engagement. N_{days} denotes the number of days with task conducted. The cell color gradient indicated the number of task types performed (etc., the darkest grey indicated a completion of all three different tasks). Users printed in green ink are those who conducted tasks for more than 10 days and were considered engaged, while users printed in red ink were deemed not engaged.

among the remaining four users who were less engaged, three reported being occupied with other commitments during the experiment period. Therefore, we considered DailyExp to be a practical tool for the continuous collection of data especially over an extended period when individuals' levels of busyness may vary. Moreover, Fig 4. (b) highlights that the ranking screen had a notable impact on the participants' engagement, as eight out of the ten users identified it as a motivating factor for conducting tasks. This observation suggests that fostering a sense of social competition could be a highly effective strategy for user engagement within such a study.

IV. Future work

In future works, we plan to expand the coverage of cognitive aspects by administrating more cognitive batteries and implement a web-based dashboard for experimenters which would allow them to easily adjust system factors and design their experiments. We expect DailyExp to be a useful tool for creating a large-scale real-world cognitive performance and physiology database. This database has great potential to contribute to the field of cognitive science by providing valuable information for understanding individual differences, intrapersonal fluctuations, and the embodied nature of cognitive processes. Potential research questions include studying the impact of human rhythms on cognitive processes across different timescales (e.g., daily circadian rhythm, monthly menstrual cycle) and identifying biomarkers of cognitive processes correlated with physiological features.

V. Conclusion

In this paper, we demonstrated DailyExp as a data collection tool for both cognitive performance and physiological data in everyday life settings. The tool was evaluated by 10 users for one-month usage and the results demonstrated its usefulness as a practical smartphone application for conveniently collecting data in daily life settings, with consistent usage by a significant portion of users and successful data collection across multiple tasks.

Acknowledgment

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