Cognitive Offloading: Accuracy and reaction times of simple tasks with technological aids

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## Abstract

People rely on technology constantly. Smartphones help people perform mathematical calculations, look up important information, schedule and attend events, and more. When using these tools, people are able to reduce their mental effort. For example, instead of mentally working through calculations, people often use calculators, which reduces the mental effort of problem-solving. This phenomena is cognitive offloading. The purpose of this study was to explore the relationship between cognitive offloading onto technological devices and simple task performance. Specifically, we sought to determine if a computer program utilizing reminders, similar to smartphone applications for scheduling events, would benefit the user's performance on tasks requiring attentional shift. We hypothesize a main effect for the use of reminders on accuracy and reaction time for the execution of simple tasks. Further, we hypothesize an interaction between the use of reminders and the number of items memorized. We found significantly faster reaction times for the reminder condition in comparison with a control condition. We did not find support for an interaction between reminder and memorization set size for reaction time or accuracy. Nor did we find additional main effects on reaction time or accuracy. Results suggest that reaction time for simple tasks involving an attentional shift would benefit from the employment of reminders.

**Literature Review**

Given the proliferation of technological tools, it is important to understand when technology benefits performance. Research is needed to develop a deeper understanding for how cognitive processes, such as "memory, attention, [and] executive function" may alter with the aid of technology (Hollan, Hutchins, & Kirsh; 2000). Furthering, our understanding of when technological aids benefit users will help produce superior technological aid designs, products, and improve user experiences.

Users use electronic devices, such as calculators, computers, and cellular devices to help store information. Calendar applications linking computers and cellular phones are frequently used to organize obligations, schedule appointments, and recall information pertaining to said appointments, such as the time and location.

Distributed cognition theory describes how mental processes, such as memory, may be spread among individuals and objects as they interact in an environment (Hollan, Hutchins, & Kirsch, 2000; Hutchins, 1995a; Hutchins, 1995b). Hutchins believed that cognition is no longer solely within the mind but within the external world as well. Information relevant to a task may be stored in multiple external forms. These forms may be present physical in the environment, such as a piece of paper, a calendar, a computer file or they may be between individuals.

Imagine you are following a daily schedule of appointments. The goal is to attend to all the obligations at their designated time. You may try to remember these items internally using your own memory or you may choose to write down the appointments time and location. By writing down appointments in a smartphone calendar we are relying on the external technological aid to execute this reminder for us, this in turn has reduced our cognitive demand

and increased our cognitive capacity. This reduction in cognitive demand is called “cognitive offloading” - physical actions that reduce the mental effort needed to perform a task (Risko & Gilbert, 2016).

Studies on cognitive offloading typically contain a condition in which participants must apply a strategy using cognitive offloading. This condition is then compared with a control, in which participants are prohibited from offloading cognitively; or participants in both conditions have their tasks (Risko & Gilbert, 2016). Furthermore, a more narrow focus of cognitive offloading is: “Intention Offloading”; which involves offloading information pertaining to prospective memory and future tasks onto an external factor (e.g. smartphone calendar, peice of paper, etc.) (Risko & Gilbert, 2016). Prospective memory is defined as “a type of memory task in which an individual must remember to perform an intended action at some designated point in the future” (McDaniel & Einstein, 2000, p. S127). An example of cognitive offloading with intention offloading in mind is a study done by Dr. Sam Gilbert where participants were instructed to drag number circles in sequences (1, 2, 3, etc.) to the bottom of the screen having them disappear once moved to the bottom of the screen; in the cognitive/intention offloading condition participants were asked to move a specific number circle (e.g. 3) to the “left” of the screen instead of to the bottom. Participants were given the option to pre-designate the number circle, in this case circle number 3, to the left area of the screen. This creates and external locational reminder, and therefore the intention is “offloaded” into the environment. As participants in the intention offloading condition move through the number sequence, once the number circle 3 appeared participants were reminded that the number circle 3 had to be moved to the “left” of the screen from the externally placed locational cue they had set at the beginning of the trial. These studies concluded that technological aids with reminders improved prospective memory and task performance.

Studies have investigated the use of physical records or external artifacts' possible influence on prospective memory (Eskritt & Ma, 2014; Risko & Dunn, 2015). Interestingly, these studies have found no significant difference on intention offloading and tasks performance when using written records (e.g. notes, to do lists, etc.). This suggests that intention offloading to a written external factors may be neither beneficial nor detrimental to cognitive performance.

Cognitive offloading is common when using computers. People interact with computer interfaces constantly. In 1988, psychologists Donald A. Norman argued that a well-designed artefact could reduce the need for users to remember large amounts of information while badly designed artefacts could increase the cognitive demands by the user. When asked to recall the names of the menus in Macintosh applications, participants were unable to recall the menu items; however in the subsequent trials participants were able to navigate through the interface and select the menu items by locational cues (Mayes, Draper, McGregor, & Oatley, 1988). This illustrates (1) individuals did not encode the names of the menu items, rather they offloaded the location of the menu items, (2) when people interact with a well-designed interface, they can accomplish their goals while engaging in cognitive offloading. The users in their experiment no longer needed to memorize the exact steps or menu names, users may offload this information and use their cognitive resources differently.

Previous work has focused on the relationship between cognitively offloading onto physical aids, (Eskritt & Ma, 2014) while other studies have studied the relationship between cognitive offloading and the strategic use of location reminders (Gilbert, 2015). Although these studies were insightful, they did not yield real-world implications of setting external reminders on technological aids, such as smartphone calendars and smartphone reminders. The majority of smartphone and computer users have applications for scheduling events and to-do lists. These devices employ customizable alarms and reminders. These applications differ dramatically from the spatial reminders employed in the studies done by Dr. Gilbert.

The current study aims to determine if technological reminders improve reaction time and accuracy as between memory loads. Thus, we hypothesize a main effect for the use of technological aids on reaction time and task accuracy for the execution of a simple task. The aim for implications of the current study is to (1) investigate the use of technological aids as a supplement for unaided memory to execute delayed intentions through intention offloading (2) investigate the relationship between reaction time and accuracy of time-based delayed intentions.

George Miller (1956) found that the average working memory is able to recall seven items, plus or minus two. Thus, we suspected that reminders are more beneficial when individuals must recall larger sets of information. Therefore, we hypothesized an interaction between the use of technological aids and the number of tasks. We expect that the technological aids will dramatically improve the reaction and accuracy for the execution of a simple task.

## Methods

*Research Design*

This project involved two independent variables. The first independent variable was onscreen reminders provided by a technological aid versus a no-reminder, control condition. This variable was implemented using a computer program. This program displayed a timer, as well as reminders to click an onscreen button at a specific time. The reminder variable was randomized between-subjects. Thus, some participants saw the onscreen reminders while others did not. The use of reminders simulated offloading cognitive information to a technological aid.

The second independent variable was the memory set size given to participants (e.g. 5 versus 10 set size). These memorization set sizes simulated the storage and offloading of varying amounts of information. Specifically, a set size of five should fall well within the average storage space of working memory for each participant. Alternatively, a set size of ten falls outside the average storage space of working memory. The tasks was randomized within-subjects.

This study used two dependent variables. The first dependent variable was reaction time measured in seconds. A timer was displayed at the bottom of the computer screen. Button clicks were assigned to certain times. Reaction time was measured as the time between an assigned time and the participants' button clicks. The second dependent variable was task accuracy. Accuracy was a ratio comprised of correct response, or hits, misses, and false alarms.

*Participants*

The participants in this study were 23 volunteer acquaintances of the researchers. Thirteen of the participants were men, while the remaining ten were women. The mean age of participants was thirty years old. All participants had used an electronic device such as a computer or cellphone to schedule appointments. Further, all participants had used an electronic device to set reminders for up and coming obligations.

*Materials*

The *demographic survey* consisted of 10 questions pertaining to the participants age, gender, gaming history, computer programing experience, and the use of electronic devices (e.g.

cellphones) for scheduling events (Appendix A). One multiple choice question asked the participants to report their gender identity. Two free response questions asked participant to report their age and number of computer programming courses completed. Four Yes/No questions asked participants to report if they played computer games, idle games, used electronic devices for scheduling purposes, and used electronic devices to set reminders. Three Likert-Scale items asked participants to report the frequency with which they played computer games, idle games, and used electronic devices with reminders. The Likert-scale responses were never, at least once a year, multiple times per year, at least once per week, multiple times per week, and every day.

The *participant instructions* described the memorization and gaming trial (Appendix B). These instructions also described how to play the *Kittens Game* as well as the goal of the game. Finally, these instructions emphasized the importance of the participants success during the game for the sake of the experiment.

Two memorization set lists were created for this study (Appendix C). Each memorization set contained a list of times, written in minutes and seconds. All times were spaced intermittently. George Miller (1956) found that the average working memory is able to recall seven items, plus or minus two. Therefore, we designed two memorization setlists sizes. One memorization setlist consisted of five times. This small set size falls well within the average working memory storage capacity. The other memorization setlist consisted of ten times. This larger set size falls outside the average working memory storage capacity.

For this study, a computer based program was implemented (Appendix E). Using *JavaFX,* the program consist of a basic user interface that display the task, a timer, and reminder. The task is represented by a button object displayed on the interface. The program displays the participant instructors, the different conditions, and memorization set lists described above. The program also keeps track of the performance of each participant by recording the reaction time of performing the tasks, and the number of hits and misses. After the program collected the users' data from each session, the program codes the data and output it into a text file with the participants id and condition as the text file title.

Reaction time is the time interval between the occurrence of an event and the beginning of the reaction to this event. In this program, time is recorded in order to calculate reaction time for the task. A pre scheduled time frame is set for the task in the session. The task have a timer that is triggered whenever the task schedule is on. The reaction time is calculated by the time spent since the task time started to until the successful completion of the task.

The accuracy of performing the task is recorded by the 'correct' or 'incorrect' button press. The task is performed by pressing the button on the screen. The program record the time that the button is pressed. The program categorize button press responses as successful, failure, or misses. If the button is pressed during the time window of the task, this task is considered successfully completed. However, if a the button is not pressed during a the time window this is considered as failure to complete the task. A miss is recorded if the participant performed no reaction (failing to press the button at all) during the time window of the task.

In technological aid conditions, the interface displayed reminder feedbacks about performing a task at a specific time. These reminders prompted to participant within 30 seconds preceding the scheduled task time and include details on the upcoming tasks [Figure 1].

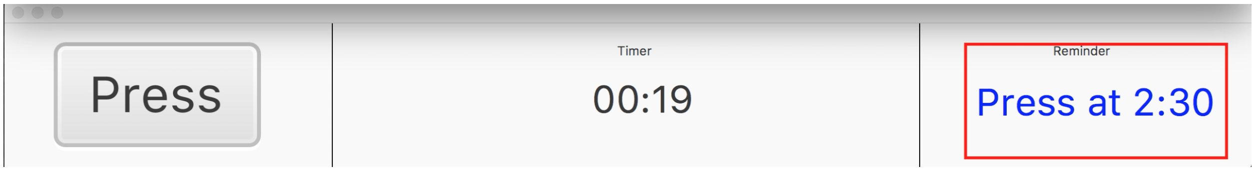


Figure 1. The designed program interface

A simple text based, slow-paced idle game will serve as a distraction task. Kittens Game is a long-planning game that requires players to click on buttons on the screen in order to accumulate resources (Appendix E). Those resources are used to build the internal economy of the kitten's civilization [Figure 2]. The slow pace of the game makes it ideal as a distraction task. Participants can easily switch between playing the game and performing the tasks without having to stop the game which will not affect the reaction time.

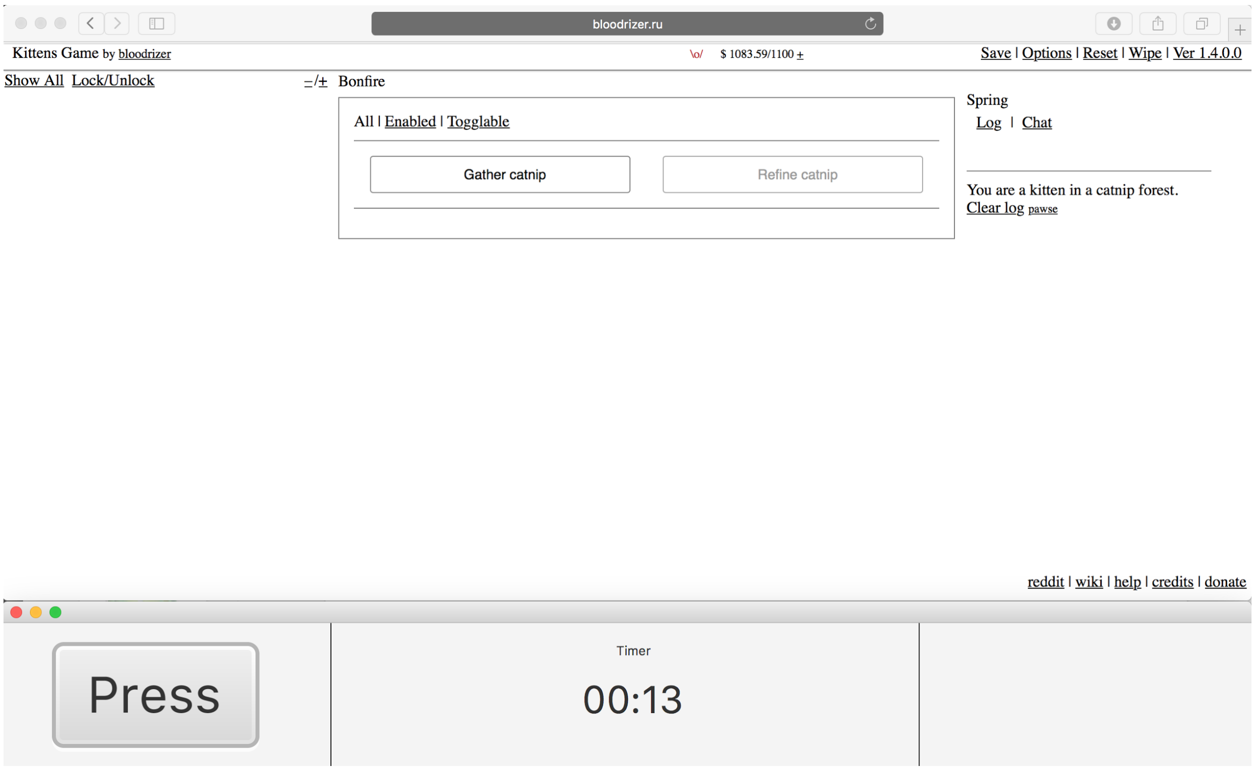


Figure 2. The Kittens game interface

*Procedure*

Participant ID numbers were randomly assigned to the memorization set size of either five or ten items. Once the experimental session began, participants completed a demographic survey. Following the demographic survey, participants read the game instructions. After reading the instructions, participants watched the demonstrational video on how to play the idle game (ongoing activity). After the video, participants began their first, three minute memorization session. During this time, the participants had  three minutes to memorize a list of set times (e.g. 2 minutes, 30 seconds). After completing the first memorization set (e.g. 10 times), participants would begin the trail, once the trial had concluded participants would complete the second memorization set (e.g. 5 times)

During the gaming trial period, participants played the *Kittens Game* for ten minutes. While playing the game, participants monitored the timer located at the bottom center of the computer screen. Once the timer struck one of the times from the memorization set lists, participants were required to click the onscreen button either from unaided memory (control condition) or aided memory (treatment condition). If the participant was assigned to the reminder condition, they would see an electronic reminder flashing in the lower right corner of the computer screen. This reminder would flash the upcoming target time (e.g. 2:30), which served to reminder participants of the impending button click. If the participants were assigned to the control condition, they  would not see a reminder. The lower right hand corner would remain empty. Once the timer displayed the memorized time, the participants would click the button located in the lower left corner of the computer screen. Each participant completed two, three minute memorization sessions followed by two, ten minute gaming trials. After completing the first trial, participants were assigned to the second memorization set and executed their second and final gaming trial.

After completing the experimental session, participants were informed as to the nature of the study. Participants were allowed to ask questions pertaining to the study. Participants were then dismissed from the session.

*Results*

Prior to statistical analysis, the dependent variable values were measured and calculated. Reaction time for each task time was calculated by subtracting the onset of the task time (e.g. 2:30 seconds) from the response time (e.g. button clicked at 2:31 seconds). An average reaction was calculated per hit. Trial accuracy was calculated by dividing the number of correct responses, by the sum of the trial set size (e.g. 5 or 10 memorization set list) and false alarms (e.g. incorrect button clicks).

Each dependent variable (reaction time, accuracy) was analysed using a 2 (technological aid) x 2 (set size) mixed design analysis of variance. The alpha level was adjusted to 0.025 per test (.05/2) using the Bonferroni method. Results from the first 2 x 2 Mixed Design ANOVA indicated that reaction time was significantly lower for the reminder condition ($M$ = 0.36 *seconds*, $SD$ = 0.07 ) compared to the control condition ($M$ = 0.84 *seconds*, $SD$ = 0.05), $F$ (1, 20) 5.77, $p$ = 0.0062. No significant interaction effect were observed between reminder and set size on reaction time, $F$ (1, 22) = 0.48, $p > 0.05$. Similarly, results indicated no significant main effect for set size on reaction time, $F$ (1, 22) = 1.16, $p > 0.05$. Results from the second 2 x 2 Mixed Design ANOVA indicated no significant interaction of reminder and set size on accuracy, F (1, 22) = 0.63, p > 0.05. There was no significant main effect for reminder on accuracy, F (1, 20) = 0.38, p > 0.05. Similarly, there was no significant main effect for set size on accuracy, F (1, 22) = 0.19, p > 0.05.

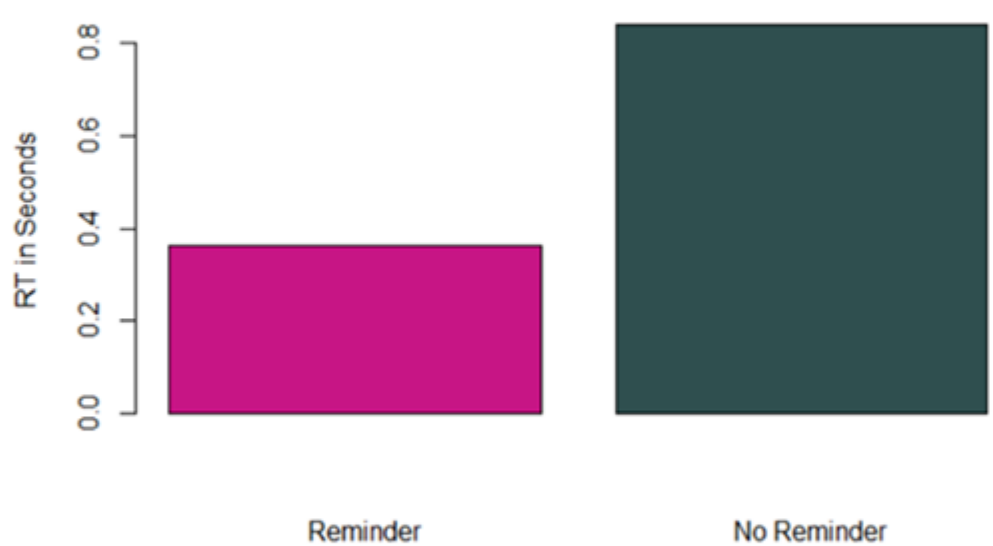

*Figure 3. Illustrates the main effect of reminder on reaction time seconds.*

*Discussion*

Results of the present study suggest that cognitive offloading onto technological aids decreased the time it took participants to click a button in response to a target time. These results suggest that the use of technological reminders, such as calendar applications on smartphones, may help improve temporal performance on tasks requiring timely responses. Results of current study indicate support for Preparatory Attentional and Memory processes (P.A.M.) Theory; in which Smith notes that individuals who are performing an ongoing activity will engage in preparatory attentional processes and reallocate their attentional resources to monitor for the cue to execute a prospective memory task (Smith, 2003). Our results showing a significant main effect on reaction time indicate that participants had to have disengaged from the ongoing activity, reallocate their attentional resources, and monitor the time to execute the prospective memory task.

Many jobs require time monitoring tasks. These findings suggest that with the use of technological reminders, individuals will allocate their attention to execute a time-based respond more quickly. Keeping in mind the results of this study, Engineering Psychology can apply these results to create more precise technological device that sets future reminders. The current study and previous research has only begun to understand the implications and real-world applications, thus these findings along with previous research are a contribution to understanding cognitive offloading as a whole.

*Limitations*

Although the current study found a significant main effect in reaction time for the use of technological aids, we do note that the current study came with faults. In our calculation of accuracy we acknowledge that our data were collapsed into one big lump calculation. Accuracy was calculated as [Accuracy = Hits/Hits+Misses] we did not take into account false alarms, where a participant hit the “Press” key when no press was required. Furthermore, the statistical analysis did not breakdown hits, misses, and false alarms separately, which could have contributed to the current results. Additionally, we recorded key presses at the seconds interval instead of milliseconds intervals, this could have also been a possible limitation as participants were given a 5 second time window to hit the “Press” key, our results on reaction time could have been more precise if we could have seen the key press in milliseconds. One of our biggest limitation in the experimental design was choosing to do a between-subjects versus a within-subjects design; it would have been beneficial to test all subjects on all conditions to compare their unaided memory with their aided memory (i.e. technological reminder). Additionally, it would have been of interest to have their subjective thoughts on the use of a technological aid versus their unaided memory, and which they would prefer and why. Another drawback to our experimental design was the way the interface was set up. Participants found it difficult to active the “Press” key window browser while playing the idle game (ongoing activity), which could have resulted in slower reaction time results. Having the “Press” key integrated into the idle game and one uniform interface could have easily corrected the issue. One interesting idea that was not taken into account was that the researchers were unaware if the participants in the treatment group memorized each of the task set-size at the beginning of the trail and completely disregarded the offloading of the tasks. Participants might have used their unaided memory similar to the control group but have the technological aid as a “back-up” or default in the event that their memory failed them. One way to correct this issue would have been to have participants in the treatment group begin the idle game and to not allow them to memorize the task-sets at all. That way participants in the treatment group would not have a chance to encode any of the task-set size and would therefore force them to use the technological aid.

*Future Research Directions*

The current study aims at identifying reaction time and accuracy; future possible directions for intention offloading can be to allow for a “Choice/No-Choice” paradigm. Wherein the control group is not given a choice to offload intention and has to rely on their unaided memory, where the treatment group is giving the choice to offload their intentions based on their own metacognitive evaluations of how well or poorly their memory is. The current study provided a “No-Choice/No-Choice” paradigm in which both treatment and control groups were not given the option to offload intentions as they see fit. Another possible direction for future research is to manipulate importance of ongoing task and intention task (prospective memory task). By placing higher levels of importance to the ongoing task we may see a cost to the intention-offloading task, or by placing higher levels of importance to the intention-offloading task we may see a cost to the ongoing task. It would be interesting to see the manipulation of importance between tasks to get a better understanding of how individuals allocate their attentional resources. A further point of interest for future research is to begin to see the mechanics behind judgements of learning; that is to see the way individuals learn and adapt when using technological aids over a repeated period of time. Does the use of technological aids begin to change our brain in such a way that we begin to accept a technological aid as an extension of ourselves? Furthermore, what long-term effects does a technological aid have on the development of the brain? These are but a few questions that cognitive offloading is eager to uncover.

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