

When multitasking, keep it simple

The influence of task complexity on disruptiveness

Master's Thesis

Human-Machine Communication

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Abstract

Multitasking is possible to quite an extent without performance being inhibited. It depends on how frequently the primary task is interrupted, the timing and duration of the interruption, the complexity of the tasks and several other factors. In this thesis the relationship between the complexity of the tasks and the degree of disruption that is caused by multitasking will be examined. As primary tasks, two variants of the child's game Memory (or Pelmanism) were used that varied in complexity. The easy variant used images and the complex variant used cards with mathematical equations. The secondary task was a kind of farm game. This was considered a complex task where participants had to fulfil orders by growing the right crops. Results showed that participants were performing a bit worse when interrupted while playing the easy Memory variant, but the influence of interruption on the performance of the complex Memory task was much larger.

Keywords: multitasking, task complexity, interruption

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Introduction

Multitasking is a regular way of working nowadays. A study that observed 24 information workers in their working environment (Mark, Gonzalez, & Harris, 2005) showed that workers experience work fragmentation as common practice. The majority of their *working spheres* were interrupted and workers spend on average 11 minutes on a working sphere before switching to another. Students are distracted even sooner. It is found that students on average spend less than six minutes on studying before interrupting themselves because of technological distractions (Rosen, Carrier, & Cheever, 2013).

Consider an information worker, working on a project. He is processing data in a spreadsheet, but then interrupts himself to check his e-mail. The e-mail he has waited for has arrived and he writes a quick response. Awaiting the answer, he returns to his spreadsheet. He searches the screen for clues trying to find where he left off, in order to resume his task. Information workers are often working on multiple ongoing projects. Often a project has waiting times, for example when continuing a task requires a response or action from someone else. During that time one could resume another project or start a new one to use their time efficiently (Aral, Brynjolfsson, & Alstyne, 2006). Of course there is a limit though, to which increasing the level of multitasking aids productivity. The relationship between productivity and the level of multitasking is shaped like an inverted-U. That means that small amounts of multitasking add to productivity, but after an optimum multitasking decreases productivity (Adler & Benbunan-Fich, 2012; Aral et al., 2006). Also, certain tasks are easier to combine than others. One is easily able to solve a crossword puzzle while occasionally stirring the soup that is warming up. On the other hand, writing an essay is less productive when the writer alternates writing the essay with writing chat messages to friends. These examples show the intuitive fact that some tasks are suffering more from interruptions than others. In this thesis the relationship between the kind of task and the degree of disruption that is caused by multitasking will be examined. Before the study is described, first a background will be given on multitasking and what characteristics influence its disruptiveness.

Background

Course of events during sequential multitasking

Interruptions are, like the example of the information worker, a form of sequential multitasking. Sequential multitasking means that the time span between the switching of the tasks is clearly longer than in concurrent multitasking, the term on the other end of the multitasking continuum (Salvucci, Taatgen, & Borst, 2009). When a task is interrupted and resumed, the overall course of events is as follows. At first a person is working on the primary task, this is the primary task performance. Then there either is an alert (e.g. phone ringing) in the case of an external interruption or the person makes the decision to switch, in case of self-interruption. After that, the person makes the actual switch and starts working on the secondary task. The time between the alert and start of the secondary task is called the interruption lag. It is suggested that during this lag, people rehearse the primary task to facilitate resumption after returning from the secondary task (Altmann & Trafton, 2002). In the case of self-interruptions, the interruption lag cannot be measured, because there is no alert. But pupil dilation research on multitasking found an increase of pupal dilation prior to the actual switch, indicating the decision to switch (Katidioti, Borst, & Taatgen, 2014). So at this point in events, the person is working on the secondary task; this is the secondary task performance. At the end of the secondary task the person switches back and resumes the primary task. The period between the switch and the first action after being back is called the resumption lag. Theories like the memory-for-goals theory and the memory-for-problem-states theory came with explanations for this lag, by suggesting this time is needed to retrieve the goal or problem state of the current task in order to resume (Altmann & Trafton, 2002; Borst, Taatgen, & Rijn, 2015). The resumption lag is one

of the negative indicators of interruptions on task performance. Without the interruption, this time would not be lost. After resuming the primary task, we can look again at primary task performance. Beside interruption and resumption lag, another interesting time interval is the inter-action interval. The inter-action interval is the average time taken to perform a single action on the primary task (Altmann & Trafton, 2004). Ratwani, Trafton and Myers (2006) found that participants speed up their actions when confronted with interruptions, resulting in shorter inter-action intervals. They tested this with simple tasks and found that the primary task was completed faster and with similar accuracy. These results suggest primary task performance could actually benefit from interruptions. Research that compared simple and complex tasks found a similar result for simple tasks (faster completion times and similar accuracy levels), but not for complex tasks which had lower accuracy levels in the interrupted condition (Speier, Valacich, & Vessey, 1999).

Interruption characteristics

The disruptiveness of interruptions in a certain multitasking scenario depends on several aspects. The influence of the level of multitasking on performance is already mentioned in the introduction. The relationship between productivity and multitasking is indicated by an inverted-U. The optimum at a medium number of switches lead to the highest productivity. Very many or few switches decreased productivity (Adler & Benbunan-Fich, 2012). The level of multitasking could also be seen as a characteristic of the interruption, namely its frequency. In this paragraph more characteristics will be explained.

Duration

Three often examined characteristics of interruptions for influencing disruptiveness are; duration, timing and complexity. Disruptiveness is often measured by looking at the resumption lags and number or types of errors. The longer an interruption takes, the more disruptive it is, indicated by longer resumption lags (Hodgetts & Jones, 2006; Monk, Trafton, & Boehm-Davis, 2008) and increase of errors (Altmann, Trafton, & Hambrick, 2014).

Timing

The second characteristic is timing. Interruptions are usually disruptive at any time, but it seems intuitive that there are better and worse moments to be interrupted. Indeed, when comparing different moments of interruption, it is found that interruptions at the end of a subtask are less disruptive than those interrupting in the middle of a subtask (Monk, Boehm-Davis, & Trafton, 2004). Explanation for this is that the end of a task or subtask is associated with a low-workload moment. Iqbal et al. (2005) found evidence for this by measuring mental workload through the use of pupil size. Most research on interruption timing is done using external interruptions, but similar results are found when using self-interruptions (Katidioti & Taatgen, 2013). When people are given the freedom to defer their switch, they tend to switch at low-workload moments (Salvucci & Bogunovich, 2010), but this behavior could change due to waiting times. When participants encounter a delay, they switch more often to the interruption task at a high-workload moment (Katidioti & Taatgen, 2013).

Complexity

Complexity is another important characteristic of interruptions that indicates the disruptiveness. If the interruption task is more complex, resumption lags are found to be larger (e.g. Hodgetts & Jones, 2006). On the other hand, research of Zijlstra et al. (1999) found that more complex interruptions did not lead to degraded performance. Interruptions even caused people to perform the main task faster, but interruptions did have a negative impact on emotion and well-being. Question is whether increasing the complexity further would give a negative effect on performance. Pilots of the current experiment showed that people are able to multitask to quite an extent. Other characteristics that determine disruptiveness are; similarity of interruption to the primary task; control over interruption engagement; and availability of retrieval cues in the primary task (see for an overview Trafton & Monk, 2007). One characteristic is especially of interest for the experiment of this thesis, namely complexity. Therefore, complexity will be examined more extensively in the next section.

Task complexity

Interruption complexity

When tasks are more complex, sequential multitasking is inhibiting performance more. Much research has investigated this by using interruptions of varying complexity. They concluded that performance is affected and resumption times increase when the interruption is of greater complexity (Cades, Werner, Boehm-Davis, Trafton, & Monk, 2008; Gillie & Broadbent, 1989; Hodgetts & Jones, 2006; Monk et al., 2008). Cades et al. (2008) specified task complexity by estimating the number of mental operations that were required to accomplish the task and indeed the interruption that involved more mental steps was found to be more disruptive. Earlier work of Cades et al. (2007) shows why defining complexity by counting the mental steps is reasonable. In their experiment they varied the complexity of the interruption tasks. The easy interruption consisted of a shadowing task, in which participants had to repeat numbers that were read to them by the computer. The other two interruptions were variations of the n -back working memory task (Lovett, Daily, & Reder, 2000), a 1-back and a 3-back task. On the surface the 3-back task appears more difficult, but when comparing the number of mental operations required; both 1-back and 3-back had three and the easy task had none. Results were in accordance to this, showing the easy task to be the least disruptive, but not showing a significant difference in resumption times between the 1-back and 3-back task. This shows that a task that appears more complex may not be more disruptive. Therefore, complexity is not a direct, but an indirect explanation of disruptiveness. If a task is more complex, more mental operations are needed and these mental operations lead to disruptiveness. Cades et al. (2007) connected this to the ability to rehearse the primary task during interruption. An increased number of mental operations decreased the ability to rehearse. The conclusion was that interruptions were more disruptive when the task minimized the ability to rehearse and not just when it was more difficult. Monk, Boehm-Davis and Trafton (2004) found similar results. Resumption lags were much longer when the interruption task minimized rehearsal compared to when interruptions allowed rehearsal.

Complexity of both tasks

Research mentioned so far all manipulated the complexity of the interruption task, but similarly the main task could differ in complexity. Speier and colleagues (2003) varied the complexity of the primary task and found a positive influence of interruptions on performance concerning simple tasks and an inhibition of performance when participants carried out complex tasks. Apparently, the complexity level of both primary and secondary task does matter. This is also something the memory-for-problem-states theory would predict (Borst et al., 2015), which is an extension of the memory-for-goals theory (Altmann & Trafton, 2002). A problem state contains information that is necessary to perform a task. There can be only one problem state active at a time. So when the primary task is interrupted by a secondary task, the problem state of the primary task is stored in declarative memory, where it is subject to decay, like other memory items. After returning to the primary task, the problem-state has to be retrieved in order to resume the primary task. This process costs some time and leads to error when an incorrect (e.g. older) problem state is retrieved. These costs are expressed in the resumption lag and are a measure of disruption. And here is why this theory involves the complexity of both tasks. There is only an effect of interruption when both tasks require a problem state. That is because one problem state can be active at a time, but when one of the two tasks is simple enough to be accomplished without problem state, the problem state of the other task does not have to be stored in memory. Therefore there is no information to decay, so there is no interruption effect.

We have seen several things about the relation between task complexity and interruption. The complexity of the interruption task affects performance and disruptiveness. This could be explained

by a limited ability to rehearse during interruption. Whereas this ability is defined in counting the number of mental operations required to accomplish the task. But not only interruption complexity is affecting performance, so is primary task complexity. The fact that both tasks determine disruptiveness could be explained using the memory-for-problem-state theory.

Hypothesis

The experiment described in this thesis examines the relationship between task complexity and the degree of disruption that is caused by multitasking. Like several other characteristics of interruptions, complexity is a meaningful indicator of disruptiveness. Complex interruption tasks inhibit performance more than simple interruption tasks. Task complexity cannot directly explain the relation between the kind of task and the disruptiveness of multitasking. The indirect explanation is; a complex task needs more mental operations and more mental operations cause a greater disruptive effect of multitasking. As described in the previous paragraph, both tasks need to be complex to cause a disruptive effect. The interruption task needs to be complex; otherwise it does not disrupt the memory of the main task enough, for example by preventing rehearsal. Also, the main task must be complex otherwise there is not enough memory to be disrupted. This leads to the following hypothesis: *“Sequential multitasking is more disruptive if both the main task and the secondary task are complex compared to when one of the tasks is not complex”*. Disruptiveness will be measured by looking at performance.

Current experiment

Two games were used for the tasks of the experiment. We looked at the primary task performance and examined how maintaining the secondary task influenced performance. To examine the relation between task complexity and disruptiveness there were two sorts of main tasks that varied in complexity. The secondary task had to be maintained, meaning it was a task that had to be attended occasionally. It had waiting times, during which the participant should make some progress on the primary task, but participants also had to be back in time to play optimal. The task setting of this experiment was a setting of sequential multitasking using self-interruptions. Participants were freely able choose when to switch between tasks, though switching needed to be planned in order to play the secondary task optimal.

Primary task

The primary tasks were two variants of the game Memory¹, also known as Concentration or Pelmanism. Memory consists of a deck of cards and players have to find pairs of the same cards. At the start of the game, all cards are arranged face down at random positions. One of the players opens two cards at a time and if there is a match the player gets a point and if there is no match the cards are placed face down again. This continues until all the pairs are found and the player with the most points wins. For the experiment we used the single player version where the player has to find as many matches as possible within the time limit.

Research done using Memory has focused on different factors influencing performance, e.g. age (Baker-Ward & Ornstein, 1988), gender (Tottenham, Saucier, Elias, & Gutwin, 2003) and the kind of stimuli on the cards (Wilson, Darling, & Sykes, 2011). Memory is also used to evaluate human spatial memory capacity (Banta Lavenex et al., 2011). These references all use Memory with images in their experiments, but Memory can also have other content. The idea to use Memory as primary task was based on previous experiments with Memory of Katidioti et al. on pupal dilation in multitasking (2014). In those experiments the Memory cards contained mathematical equations instead of pictures. This variant of Memory was also used by Anderson et al. (2012). Equation Memory requires

¹ To avoid confusion between the game and the mental structure memory, the game Memory will be written with a capital M.

high-level cognitive operations involving symbol manipulation. That makes it a more complex task than Image Memory, where only visuospatial information has to be collected. For Anderson's experiment this was important because participants had to be slow, because imaging data was used to track participant's trajectories. Iqbal and colleagues (2005) have investigated the mental workload imposed by several tasks. The main cognitive subtasks in their *Interactive route planning task* were store, recall and computation. One of their conclusions was that computation subtasks induce more mental workload on a user than store and recall. This aids the prediction that Equation Memory is more complex than Image Memory. Because of this difference in task complexity between Image Memory and Equation Memory, we used them both as primary tasks to examine the relation between task complexity and disruption.

Secondary task

The secondary task, or interruption task, was a kind of farm game where participants had to fulfil orders by sowing and reaping the right crops. The growing of the crops took some time and participants were instructed to use that time to switch back and make some progress on the primary task. After the crops were fully grown, they eventually withered, so participants had to be back in time. This aspect made this task a prospective memory task, because each time they returned to the primary task they had to make a mental note to return to the farm game in time. To test the hypothesis, the secondary task has to be a complex task. The farm game task is considered a complex task, because it requires several processes like interface interaction, calculations and rehearsal. Several actions are needed to sow, reap and send orders. Also, participants have to calculate how many of what kind of crops are needed to fulfil an order and the orders have to be remembered (and rehearsed) because there is at most one visible at a time.

Measuring performance

The hypothesis states that sequential multitasking is more disruptive if both the main task and the secondary task are complex. Disruptiveness will be measured by looking at performance. Therefore it is important to operationalize performance. The focus will be on primary and not on secondary task performance. Adler and Benbunan-Fich (2012) divided performance into productivity and accuracy. Since the two primary tasks are Memory games, productivity will be measured by calculating the score speed. This means the score earned per minute. Matches add to the score and clicks subtract points, to discourage random clicking. Accuracy is often measured in the number of errors. In a Memory game, an action cannot be exactly wrong, but if a person keeps visiting cards that already have been viewed this indicates the person has forgotten the cards and this indicates a loss of accuracy. Viewing a card for the second time (or more) is called a 'revisit'. So counting the revisits per game, gives an indication of how many cards were forgotten during the game and therefore an indication of accuracy. Revisit is a more direct measurement of performance than score. Score is build up from two things including revisit. Lower accuracy and productivity show that performance is disrupted.

Methods

Participants

Thirty participants (16 females) participated in the experiment. Their ages ranged from 18 to 28, the mean age was 22.6. Participants received a monetary reward of 10 euros. All participants gave informed consent before the experiment started.

Primary task

The experiment consists of two primary tasks; Image Memory and Equation Memory. In Figure 5 and Figure 6 in Appendix A screenshots of the tasks can be found. In Image Memory the cards contain images. A match is made by two cards that represent the same object. So the images are different, but the object they represent is the same, e.g. a car (Figure 1). The reason we have chosen to not use matches that have the same image is to stimulate rehearsal in a verbal way. If the images are not the same photographic memory is less straightforward and because matches represent an object that would stimulate participants to rehearse the name of the object instead.



Figure 1 - Two card examples of Image Memory and one of Equation Memory

The other kind of Memory is Equation Memory. The cards of equation memory contain equations of one of these forms: $aX=b$, $X+a=b$ or $X-a=b$, where X is the unknown variable and a and b are numbers. Equation memory was used in another multitasking-experiment (Katidioti et al., 2014) where equations of this form corresponded to medium difficulty. Two cards match when they represent the same value of X . For example, $X+3=8$ and $2X=10$ are a match, because X is 5 in both of them. Both kinds of memory are played with 24 cards (12 pairs). In equation memory a is a number between 0 and 9. When X is 12 then a has a maximum value of 2 when the calculation to the solution of the equation involves division. In this experiment there is only one player and the turning of the cards is adapted to reduce the complexity of the game. In this way the analysis will also be simpler. The adaptation means that a participant turns one card at a time and there are at most two cards open. For example, the participant turns a card and inspects it. Then the participant turns a next card, there are now two cards open. If there is a match the cards are placed face down again and the string 'Matched!' appears on the cards. If the two cards were no match, the participant turns the next card. By doing that, the card that was turned the longest ago is turned face down again, so that there is always a maximum of two cards open at a time.

Secondary task

The secondary task of this experiment is a time-based prospective memory task. This task is a kind of farm game where participants have to fulfill orders by sowing and reaping the right crops. It costs time for the crops to grow and during this time participants are supposed to switch back and play Memory again. The prospective memory aspect of this task is that participants have to plan and remember to switch back in time to harvest their fully grown crops. They have to be back in time because fully grown crops wither if they are not harvested in time. The growing time of crops varied

between 16 and 24 seconds drawn from a uniform distribution. Appendix B shows the farm game and the growing and withering of the crops. The main goal of this task is to send fulfilled orders to gain points. Each order asks for a different combination of crops, for example 3 flowers and 4 grapes. Already harvested crops are stored in 'storage'. It requires some reasoning to decide what crops have to be sown based on what is needed for the order and how much is already in storage. To make it even more difficult one can choose from three orders at a time. The orders are face down unless you click on one to see its content. This adds a little rehearsal, because there is at most one order face up at a time.

Procedure

The participants' objective was to maximize their score. This score included Memory and Farm game points. They were free to allocate their time between the two tasks and choose a strategy to maximize their score. To perform the main task participants had to click on a card to turn it. The card showed then the image or equation (depending on the Memory type). For Image Memory they had to remember the object the image represented. For Equation memory they had to solve the equation and remember the value of X. They continued by clicking a new card. If in Image Memory the clicked card matched the card that was previously clicked both cards turned grey, a string 'Matched!' appeared over them and the cards could not be clicked again. Also ten points were added to the score of the participant. When the click resulted in a match in equation memory the cards were faced down again and the string 'Matched!' appeared on their back and the cards could not be clicked again. Also, 16 points were added to the score of the participant. When a card was clicked by a participant, this could be either a "new card" (when it was opened for the first time), a "revisit" (a card that had been opened before) or a "match" (when the card matched the previous card that was opened). We considered a match to be a lucky match when a card was opened for the first time and it matched the card that was already open.

Switch to Farm Game

To switch to the secondary task participants had to click the button 'Farm game' on top of the screen. Switching back could be done by clicking the button 'Memory'. After 60 seconds after the start of a block a warning message would appear if the participant had not switched yet.

A screenshot of the farm game is shown in Appendix B. The farm consisted of six fields where the seeds could be sown. To sow seeds participants had to click on the button representing the right seed and the cursor image would turn into that seed, indicating it was selected. After that, they had to click a field to actually sow the seed. When all six fields were sown, the timer would start and a progress bar indicating the growing time would appear. Left of the fields, the orders were shown. The three orders were placed face down and at most one could be opened at a time. To open an order and watch its content participants had to click on it. When the growing time was fulfilled, the crops were fully grown. To harvest crops participants had to select the harvest tool by clicking the button above the fields. When the harvest tool was selected the cursor image showed the harvest tool and harvesting a crop was done by clicking on the field. Harvested crops were added to the storage. If there were enough crops in storage to fulfill an order, participants had to open that order and click one more time to send it. After being sent the order turned green, was turned face down and the phase "Sent OK" appeared on the back. After it was sent, the points of that order were added. The points that could be earned differed per order depending on the number of crops they required. To prevent participant from hoarding crops a maximum was set and shown on the storage. When the maximum of 20 crops was reached, the box depicting the storage turned red and no new crops were added.

Design

The experimental design was within-subject. Participants had to complete 4 blocks of 15 minutes.

Half of the blocks were having Image Memory as main task and in the other two blocks it was Equation Memory. From the two blocks one was the control condition and the other was the switch condition. In the control condition participants only had to play the main task (Memory). In the switch condition participants had to use sequential multitasking to do both the primary and the secondary task. To reduce the influence of learning effects on the data, the order of the conditions was changed systematically and therefore every participant performed the blocks in a different order. Because there are only 24 sequences for four conditions and there were 30 participants, some orders are used twice.

A block ended after 15 minutes and a message appeared informing the participant about the combination of tasks in the next block and showing their score on the last block. Within a block when all the Memory pairs were found a new Memory game would start, but the farm game would continue and would not restart during the block. In the upper left of the screen participants could view the total score of both games for that block. The buttons on top of the screen that allowed the participant to switch were only shown in the switch condition. Before the experiment started, participants were allowed to practice in a setting where all three games were available. They could switch between the games and try them until they understood how to play them. When they understood, they would click the button “I understand the games, start the experiment” (for screenshot see Appendix C). The instructions that were given can be found in Appendix D.

Measuring performance

Performance is operationalized as productivity and accuracy on the Memory task. Productivity is measured by calculating the score speed, meaning the number of memory points a participant earns per minute. For the control conditions this means taking the total memory score of the block and dividing it by the block length in minutes. For the switch conditions the total block memory score was divided by only the minutes that a participant actually played Memory, the time spent on farming was already subtracted. The score is built up from the number of matches and the number of revisits. In Image Memory each match gives 10 points and in Equation Memory each match gives 16 points. Matches in equation memory are worth more points because that memory is harder and we didn't want participants to only focus on the farm game because they had the impression there was not much to earn at the equation game. For each click 1 point was subtracted from the score to prevent people from using randomly clicking to find matches. Accuracy is measured by examining the number of revisits. The number of revisits is counted and the number of revisits per game is taken as a measurement of accuracy.

Pilots

The project which resulted in this thesis started with several pilots. The main interest was looking at the influence of multitasking on performance. Main conclusion from the pilots was that it is not that easy to make people perform less. Because these pilots have greatly contributed to the final research direction we will give a brief summary of the process. In the beginning the plan was to focus in particular on the prospective memory aspect of the secondary task. An interesting question was whether the mere thought of a task that had to be attended in the future would influence performance, like was found in other research (Hicks, Marsh, & Cook, 2005; Smith, 2003).

First pilots

The cards of Memory in the first pilot contained smileys and the only thing participants had to do at the farm game was clicking the six fields to sow crops and after some seconds click the fields again to harvest them. The results didn't indicate any influence of multitasking on performance.

Therefore we decided to increase the difficulty of the farm game. Now there were two kinds of crops: grapes and flowers. And each time one had let a grape wither a flower had to be sown on that field one time. And to harvest one now had to select the harvest tool before clicking the fields. For Memory we changed the smileys to images of objects. Two cards didn't have to be the same to be a match, but the images had to represent the same object, e.g. a car. Those objects should trigger participants to remember the images by their names instead of only by their sight. In that way rehearsal by use of a phonological loop was an option. But also at this pilot there was no indication of an effect of multitasking on performance. There were also no indications that participants actually used rehearsal. It seemed just as easy to learn photographic pairs. When the first card of a pair had been seen, one would remember how the second card would look.

Adding equation memory

Our pilots with Image Memory didn't indicate an effect of multitasking on performance. Therefore, we added Equation Memory to the experiment to compare it to Image Memory. And indeed, according to the results, Equation Memory was found to be more difficult than Image Memory by resulting in a lower score. But the main factor, multitasking, was still not showing to affect the Memory score per minute, neither for Image Memory nor Equation Memory. In subsequent pilots we varied some parameters, but mainly increased difficulty of the secondary task. As it turns out, it is not so easy to make people perform less. Eventually, with a small indication of effect on the pilot we decided to conduct the experiment with 30 people instead of the small sample size used in the pilots.

Results

The participants were told their objective was to optimize their score. This score included Memory and Farm game points. They were free to allocate their time between the two tasks and choose their own strategy of optimizing their score. Therefore, though a lot of clicking was discouraged by means of subtracting points, we did not remove participants who did so. The only requirement for the results was that the participant completed at least one game per condition. Because all participants met this condition, no participants were removed.

Our hypothesis specifically involves the performance on the main task and therefore the results will be focused on the Memory game. Behavioral data of the experiment is shown in Table 1. Here follows some explanation of the measurements in the table. The score per minute (SPM) is calculated by dividing the total number of points earned in a block by the time spend on Memory in that block. Other 'speed' measurements of units per minute are calculated in similar ways. The measurements per game are calculated by dividing the unit (e.g. clicks) by the total number of completed games in a block. The control conditions are depicted with the word 'control' and the condition with the interruptions of the secondary task are called 'switch'. For revisits per game the median is displayed instead of the mean, because of its skewed distribution. Equation Memory was more complex than Image Memory. Interesting is to see whether participants tried to compensate for that by trying to focus more on the Farm Game during Equation Memory. The mean Farm Scores do not show such a strategy as they are of comparable high in both conditions. While combined with Image Memory participants earned 1024.5 (SD=416.6) points per block and 1042.7 (SD=404.5) when combined with Equation Memory. Also the percentages of time spend on Memory and the number of switches were comparable between the two switch conditions. During the switch condition with Image Memory 58.9% of the time was spend on Memory with a mean of 26.5 (SD=7.75) switches, compared to 58.0% and 25.7 (SD=8.03) switches with Equation Memory. The two Memory Games are well comparable, because participants performed similar on the Farm Game in both conditions.

Table 1 - Behavioral Data (Mean (SD))

	Average	Condition			
		Image Control	Image Switch	Equation Control	Equation Switch
Percentage of time played Memory	-	100% (0)	58.94% (12.09)	100% (0)	57.96% (12.60)
Score per minute (SPM)	44.44 (20.32)	56.29 (16.80)	54.58 (18.15)	37.77 (13.63)	29.12 (18.89)
# of games per minute (GPM)	0.65 (0.37)	0.97 (0.17)	0.98 (0.18)	0.33 (0.11)	0.30 (0.14)
# of matches per minute (incl. lucky matches)	8.11 (4.36)	11.88 (2.04)	12.26 (2.15)	4.20 (1.30)	4.11 (1.66)
# of lucky matches per game	0.82 (0.56)	0.84 (0.44)	0.84 (0.36)	0.87 (0.60)	0.75 (0.77)
# of revisits per game (RPG) (median (SD))	33.70 (32.25)	28.76 (10.80)	31.68 (11.51)	40.70 (25.68)	56.50 (46.45)
# of clicks per game (CPG)	72.07 (32.15)	63.06 (10.74)	66.08 (11.44)	80.86 (25.56)	106.25 (46.21)
# of switches	-	0 (0)	26.50 (7.75)	0 (0)	25.67 (8.03)
Farm score per block	-	0 (0)	1024.5 (416.6)	0 (0)	1042.7 (404.5)

Score per minute

The two factors that were varied in the design of the experiment were *Game* and *Interrupt*, meaning respectively the kind of memory game and whether or not there were interruptions. Game could be either 'Image' or 'Equation'. Interrupt could be either 'switch' (condition with interruptions) or 'control' (no interruptions). An important measurement is the score per minute (SPM). It can be seen

in Table 1 that the SPM of Image Memory is much higher than the SPM of Equation Memory, 56.29 against 37.77 for the control condition and 54.58 against 29.12 for the switch condition. Looking within the games, the SPM of the control condition of Image Memory is a little bit higher than the switch condition (56.29 against 54.58). For Equation Memory this difference is larger (37.77 against 29.12). The line graph in Figure 2a shows this difference of Game and small difference concerning Interrupt.

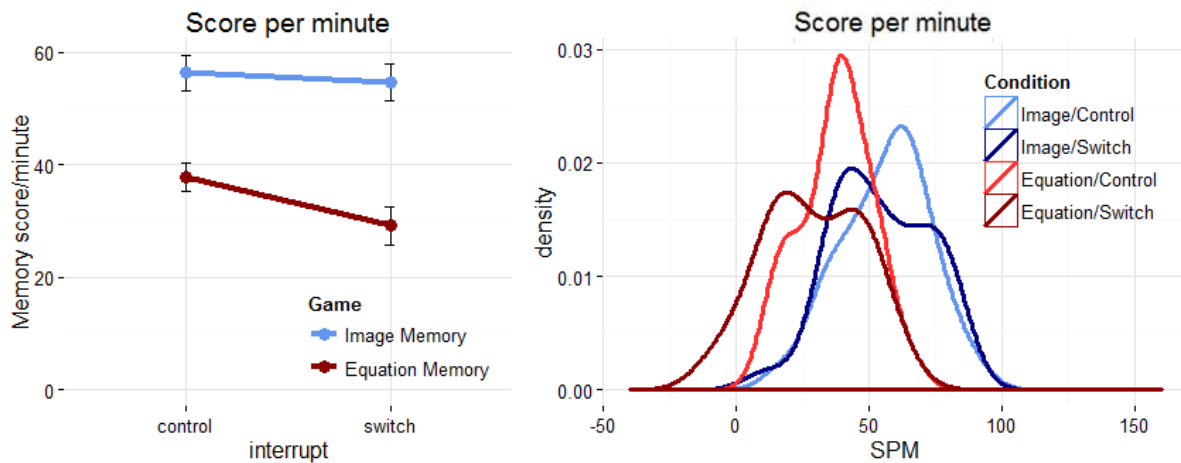


Figure 2 (a) The score per minute means and error bars and (b) the distribution of score per minute

When looking at the density distributions of SPM (Figure 2b), some observations can be made. The considerable overlap between the distributions of Image Memory (blue in the graph) makes it difficult to see whether Interruption caused a shift of the mean. The distributions of Equation Memory show a clear shift to the left, indicating a drop of SPM in the switch condition. The distribution of the switch condition is also wider, indicating an increase of individual differences. This is less visible in the switch condition of Image Memory, though their shapes are alike. So, Interrupt causes a clear shift with Equation Memory and not such a clear one for Image Memory. This difference in magnitude of shifts indicates an interaction effect of Game and Interrupt, as also indicated by the line graph where the two lines are not entirely parallel. It seems the influence of Interruption on Equation Memory is larger than on the SPM of Image Memory.

We performed a two-way repeated-measures ANOVA² including interaction, with the two fixed factors Game (two levels: Image Memory and Equation Memory) and Interrupt (two levels: control and switch). No obvious deviations from homoscedasticity or normality were found during visual inspection of residual plots. For all tests in this thesis an α of 0.05 is used. The ANOVA showed a significant effect of both Game ($F(1,29)=62.16, p<0.001$) and Interrupt ($F(1,29)=6.36, p<0.05$). And in spite of the indication of the plots, the ANOVA did not confirm a significant interaction effect of Game and Interrupt ($F(1,29)=3.08, p<0.1$). One possible reason for this is that a score difference with high scores (like in Image Memory) has relatively less influence than with low scores (Equation Memory). A solution to reduce this effect is by normalizing the scores. The SPM of Image Memory in the control condition is 1.49 times larger than the control scores of Equation Memory. Therefore, the SPM of Equation Memory is multiplied by 1.49. When applying the same two-way repeated-measures ANOVA to the normalized data, there is a significant interaction between Game and Interrupt ($F(1,29)=4.29, p<0.05$). There is no effect of Game anymore, because the games are normalized to each other and the effect of Interrupt is the same. SPM is an indirect measure,

² All statistics are done using R (R Core Team, 2015)

influenced by both the number of matches and revisits. In the next section we will look at the more direct measure of performance, the number of revisits.

Revisits

Revisits are an indication of memory loss. A card has to be visited again, because the participant has forgotten what its content was. We will now look at the number of revisits participants took during a game. The number of revisits per game (RPG) is averaged per subject and only completed games are taken into account. The line graph in Figure 3 shows the means and standard errors of RPG.

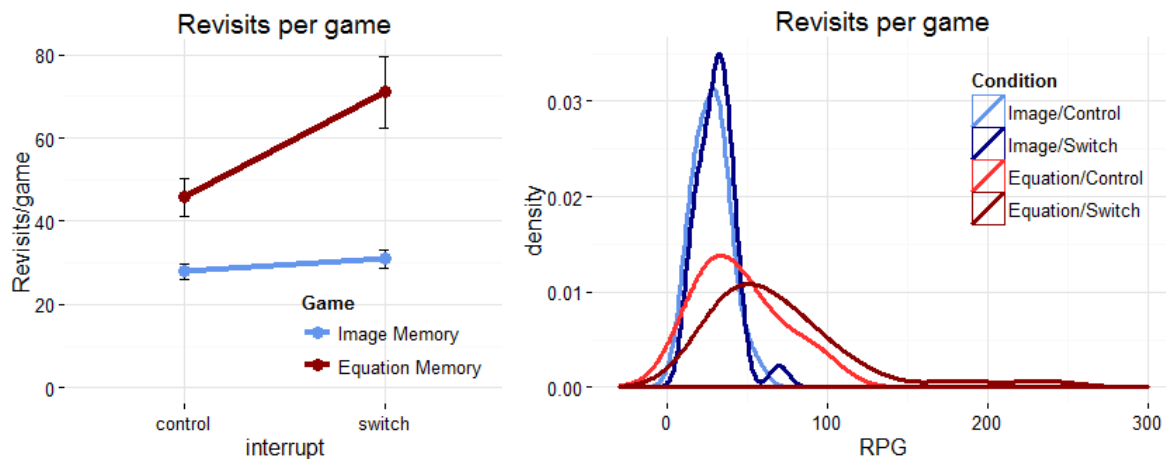


Figure 3 (a) The revisits per game means and error bars and (b) the distribution of revisits per game

Both conditions in Image Memory have lower RPG than Equation Memory, 27.91 against 45.73 for the control condition and 30.92 against 71.01 for the switch condition. When we look at Interruption concerning Image Memory there is a tiny shift of the mean; 27.91 in the control condition against 30.92 in the switch condition. A shift that is almost invisible at the density plot in Figure 3. There we see a small tail appeared in the switch condition. The distributions of RPG of Equation Memory are wider, with a large tail at the right. The distribution of the switch condition is wider and has a heavier tail than the control condition, indicating more individual differences. A clear shift of the mean RPG is visible when comparing the two conditions of Equation Memory. The number of revisits increased in the switch condition, indicating memory problems. This increase is larger for Equation Memory compare to Image Memory as can be seen in the line graph (Figure 3a). This possible interaction effect can also be concluded from the fact that the lines of the games are not parallel in the line graph.

We performed a two-way repeated-measures ANOVA including interaction. To reduce the influence of the right tail of RPG, we used a log transformation of RPG. The two fixed factors were Game and Interrupt. No obvious deviations from homoscedasticity or normality were found during visual inspection of residual plots. The ANOVA showed a significant effect of both Game ($F(1,27)=45.77$, $p < 0.001$) and Interrupt ($F(1,28)=28.51$, $p < 0.001$). Also the interaction of Game and Interrupt was significant ($F(1,29)=13.81$, $p < 0.001$), indicating a different effect of interruptions on each game. These three effects were also significant without the transformation of RPG.

Other measurements

Inter-action interval

SPM and RPG showed that the performance dropped in the switch conditions in terms of respectively productivity and accuracy. The inter-action intervals show that participants were not slower in the switch conditions. The line graph in Figure 4 clearly shows that the inter-action intervals in the switch

conditions were shorter than in the control conditions. This effect of Interrupt is especially strong for Equation Memory.

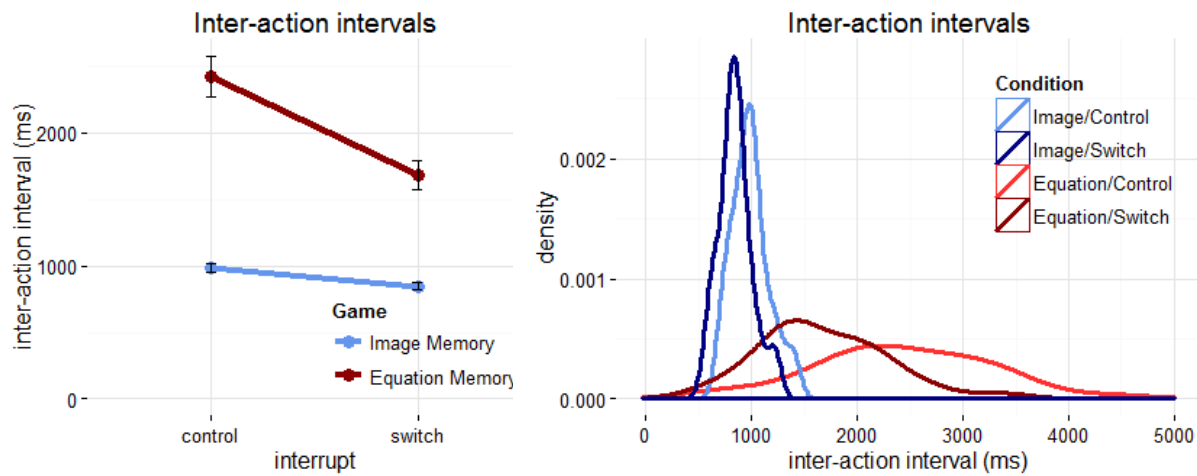


Figure 4 - (a) The inter-action interval means and error bars and (b) the distribution of the inter-action intervals

A two way repeated-measures ANOVA using Game and Interrupt as factors showed effects of Game ($F(1,29)=97.55, p<0.001$), Interrupt ($F(1,29)=78.8, p<0.001$) and an interaction effect ($F(1,29)=40.04, p<0.001$). The interaction effect is pretty strong, so participants really speed up their actions when they had to multitask during Equation Memory. Ratwani, Trafton and Myers (2006) also found this effect, though they especially tested it with a simple task. In the current experiment we see that with a complex task this effect is even stronger. Another result from the experiment of Ratwani et al. was that the average resumption lag in the interrupted condition was longer than the average inter-action interval of the control condition. This meant that though the overall inter-action intervals in the interrupted condition were shorter, the first action back at the primary task was hindered by the interruption. This is not something found in our data. We measured resumption lag by looking at the time interval between the switch back to the primary task and the first action back on the primary task. Resumption lags were not longer, but shorter than the mean inter-action intervals of the control condition. With a mean resumption lag of 1421 ms ($SD=658$) and an inter-action interval of 1705 ms ($SD=936$).

Switches and Farm Game observations

An average visit to the Farm Game lasted 14.8 seconds ($SD=13.36$). Visiting lengths were similar between the two games; 14.3s ($SD=15.7$) for Image Memory and 15.23s ($SD=10.4$) for Equation Memory. The mean visits on Memory were a bit longer; 18.6s on average. The averages of the games were equivalent; 18.8s ($SD=15.3$) and 18.4s ($SD=16.0$) for respectively Image and Equation Memory. This is predictable because the length of the Memory visits did not depend on the Memory task but on the growing time of the crops. The growing times were drawn from a uniform distribution with values between 16 and 24 seconds. This means participants should on average be back within 20 seconds, somewhat later than the measured average of 18.6 seconds.

In the background was mentioned that when people are given the freedom to defer their switch, they tend to switch at low-workload moments (Salvucci & Bogunovich, 2010). Can that behavior also be identified in our data? The times after a match, lucky match and a switch back were counted as low-workload moments. Because (lucky) matches decrease the memory load and when one switches back directly after a switch there is not yet new Memory information to attend to. That leaves visits and revisits to be high-workload moments to switch. Table 2 shows the percentages of switches at low- and high-workload moments. There we can see that with Image Memory participants tend to switch more than half of the time at a low-workload moment.

Table 2 - Percentages of switches at low- and at high-workload moments

	Switch at low-workload moment	Switch at high-workload moment
Image Memory	57.9%	42.1%
Equation Memory	30.4%	69.6%
Average	44.4%	55.6%

In Equation Memory and therefore in the average there are not more switches after a low-workload moment. Do these results say anything about the preference of participant to switch at a high- or low-workload moment? We cannot conclude that from this data. One explanation why there are not more switches at low-workload moments during Equation Memory is that there are just not so many low-workload moments compared to high-workload moments. The number of matches made during Equation Memory is much lower than during Image Memory and also the Farm Game demands participants to switch within a certain time interval.

The numbers of good and bad harvests were counted as they are an indication of accuracy for the Farm Game. Percentages showed that participants were often on time as 82.8% of the harvests were good harvests. Percentages do not differ much between the two games. 81.5% (SD=19.6) of the harvests were good harvest during Image Memory and for Equation Memory that was 84.1% (SD=14.6).

Discussion

To examine the relationship between task complexity and the influence of interruptions on performance we conducted an experiment using two primary tasks that differed in complexity combined with a complex interruption task. The results showed that participants were performing a bit worse when interrupted while playing the easy Memory variant, but the influence of interruption on the performance of the complex Memory variant was much larger. A result that was visible in the line graphs and confirmed by the interaction effect between Game and Interrupt that was significant in both SPM and RPG. This supports the hypothesis of this study that *“Sequential multitasking is more disruptive if both the main task and the secondary task are complex compared to when one of the tasks is not complex”*. Equation Memory was the task we classified as the complex task and Image Memory as being easier. It is important for conclusions about the hypothesis that the results reflect this categorization. Therefore we will first discuss the complexity of the primary tasks as found in the results. Then we will give an explanation for the main results concerning the hypothesis. And after that some aspects of the experiment design will be discussed as well as directions for future research.

The results confirmed the categorization of Equation Memory being more complex than Image Memory. This was expressed in Equation Memory having a lower average of score per minute (SPM), more revisits and longer inter-action intervals. The SPMs are actually difficult to compare between the two kinds of Memory, because each gave a different amount of points to a match. In Equation Memory a match was worth more (16 points), compared to Image Memory (10 points). When looking at the results though, this fact actually increases the confidence that Equation Memory is harder. Because even though participants earned fewer points per match, their score of Image Memory is still higher. The larger number of revisits in Equation Memory reflects the observation that Equation cards are easier forgotten. When playing with Image cards the picture and location are just stored in memory, without the need for active rehearsal. They are only subject to decay like other items in memory. Equation cards on the other hand need active rehearsal and therefore require more effort to be remembered. The longer inter-action intervals of Equation Memory reflect the effort it costs to take a step in Equation Memory. Steps in Equation Memory require beside the usual subtasks of store and recall the extra subtask calculation. Calculation also induces more mental workload than store and recall (Iqbal et al., 2005).

An important observation for the reliability of comparing the two primary tasks despite their difference in complexity was that the scores of the Farm Game were of comparable high in both conditions. Also the percentages of good harvests were equivalent and also the time that was spend on the Farm Game. Therefore, we can conclude that participants did not focus more on the Farm Game in one of the two conditions. Something they could have done to compensate for example for the fewer points earned in Equation Memory.

As we have seen, the interruption effect on performance was much larger for Equation Memory. An explanation for this could be that both Memory variants require a different memory strategy. Like explained in the previous paragraph; Image cards do not need active rehearsal where Equation cards do. This protects them against interruptions. Though normal decay in declarative memory could cause some decrease in performance due to an interruption. Equation Memory on the other hand requires one to actively rehearse the numbers of the solutions. Therefore, when an interruption is complex enough that it causes this rehearsal to stop or be suppressed, it causes a great disruption. This is in line with earlier research that suggested that it is the ability to rehearse that is critical in how well an interruption is handled and not just the complexity of the interruption task (Cades et al., 2007; Monk et al., 2004).

The results of the current experiment are in line with what the memory-for-problem-states theory would predict. The theory states that there is only an effect of interruption when both tasks are

complex enough to require a problem state (Borst et al., 2015). If one of the two tasks is simple enough to be accomplished without a problem state, the problem state does not have to be stored in memory. Therefore there is no information to decay, so there is no interruption effect. This would be the case with Image Memory which requires no problem state as the image and location of a card could directly be saved in declarative memory.

In the process of the pilots we kept increasing the complexity of the Farm Game to see eventually performance being degraded. We can learn from this that people are able to multitask to quite an extent. Also, this is in line with the hypothesis that not only the primary task needs to be complex (e.g. Equation Memory), but also the Interruption task, to cause a disruption of performance. We have to keep in mind though that the pilots were done with small amounts of people and therefore these observations only bare small weight.

A notable aspect of the distributions of SPM was that it was wider for the switch conditions, especially for Equation Memory. This depicts more individual differences. Probably participants used different compensating strategies to cope with the interruptions. This is also visible in the number of revisits distributions of Equation Memory. We have referred to an increased number of revisits as being a sign of memory loss. But is this loss of memory only due to memory interference from the interruption or could this also be due to a choice of participants to change their strategy? In those cases people chose to put less effort in remembering and chose to use more clicks. So, individual differences increased when participants had to deal with interruptions. But even in the control conditions people are acting different from each other. Though the overall conclusion is that Equation Memory is harder than Image Memory, there are individual differences. The same task can be easy for one person but difficult for another. Especially a task as calculation solutions to mathematical equations is not often encountered in daily life. And therefore the area of study or work could give some persons an advantage. Also strategies can be personal. Someone who is not so good in Memory might click more. Therefore it was important that we conducted a within-subject study, to rule out these individual differences.

Although the main interest in this study was measuring performance through Memory score and the number of revisits. It was interesting to see that participants speed up their actions when confronted with interruptions, which was reflected in shorter inter-action intervals of the primary task. This effect was also found in an experiment of Ratwani et al. (2006) where it was seen as a benefit of interruptions because participants were not only faster, they also made fewer task critical errors during the interruption conditions. However, their experiment was only done with a simple task. Other research showed this does not hold for complex tasks (Speier et al., 1999). And indeed though participants really speed up during the switch condition of Equation Memory, their performance clearly suffers from the interruptions. An explanation could be that quicker actions are actually not beneficial for Equation Memory. It costs time to calculate an equation solution and store it in memory. When stressed due to the interruptions, it could be that one takes too little time to memorize the equation card well. This would also be an additional explanation for the increase of revisits, because when the equation cards don't get enough attention to remember them well, they will easily be forgotten, resulting in extra revisits.

The behavioral data from this experiment shows that task complexity influences the disruptiveness of interruptions, as the effect of interruptions were much larger when both tasks were complex instead of only one of the two. We have given an explanation for these results by looking at the task characteristics. In the future it would be easier to take two tasks that are easier to compare, e.g. Equation Memory with three levels of difficulty. This experiment has shown there is an increase of disruptiveness when tasks are more complex, but further research is necessary to secure the explanation we have given for this effect. Research that identifies the exact mental resources used in the tasks, especially in the Farm Game is needed to tell apart for example the influence of task complexity and similarity of interruptions to the primary task. Our focus has been on complexity, but

that is just one aspect of many factors that influence people's ability to deal with interruptions. And this aspect alone cannot fully explain what makes different interruptions to be more or less disruptive.

Also, this experiment gave little insight in the internal decisions and strategies of the participants. We did not give a questionnaire or ask participants why they acted like they did to discover what kind of coping strategies they used to deal with the interruptions.

The findings of this study give hope and cause for caution. On the one hand the process with the pilots and the minor inhibition of performance with Image Memory indicate that people are actually able to multitask to quite an extent. It is not so easy to let participants perform worse. This is good news for our society today, in which multitasking is an everyday experience. On the other hand did the complex Memory variant show that in combination with a complex interruption task it is not possible to keep the same level of productivity and accuracy.

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Appendix A



Figure 5 - Screen shot of Image Memory

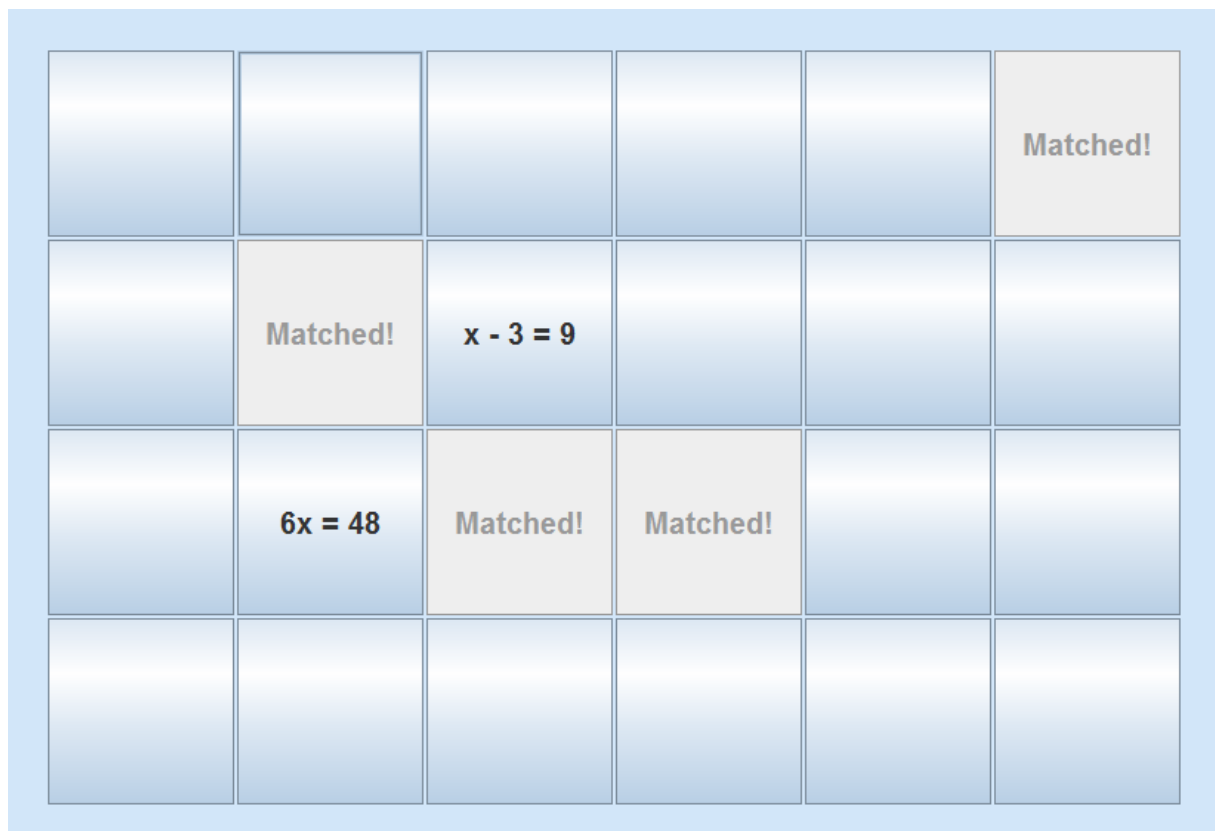


Figure 6 - Screenshot of Equation Memory

Appendix B

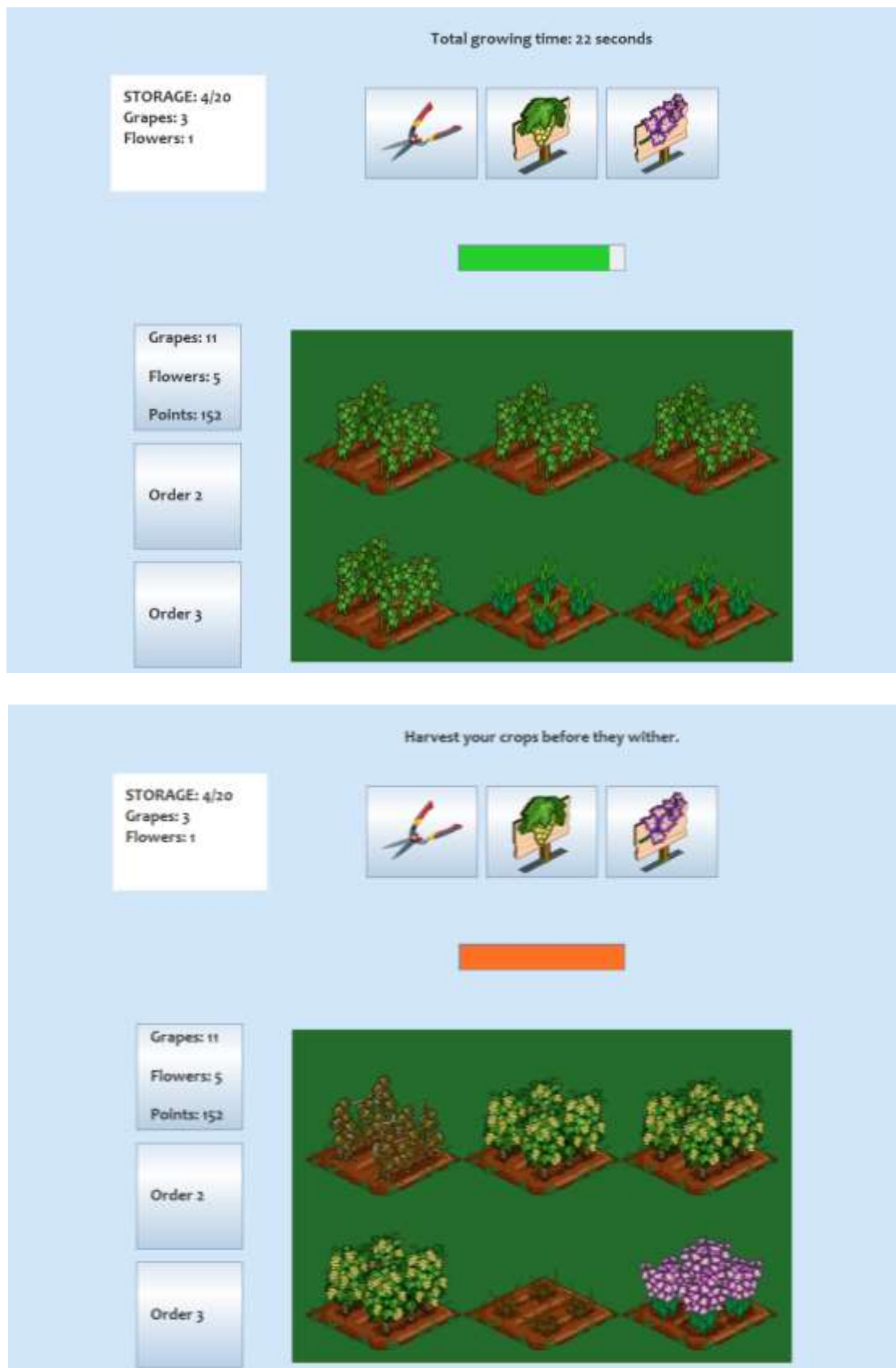


Figure 7 - (a) Farm Game in growing phase, (b) Farm Game fully grown, some crops are already withering

Appendix C



Figure 8 - Screenshot of farm game (during practice)

Appendix D

INSTRUCTIONS

Instructions for the study “Sequential multitasking while playing a Memory game” performed by Maaike van de Wetering.

Welcome to this experiment about sequential multitasking while playing a memory game. During this experiment you are going to play two kinds of memory and one other game. Sometimes you have to play only memory and sometimes you have to play memory and the other game by switching between them. You can earn points by playing the games and your goal is to **maximize your score**.

The two kinds of memory are ‘memory with images’ and ‘memory with mathematical equations’. The goal of the **memory game** is to find as many matches as you can before the time is up. You open a card by clicking on it and then the image or equation is shown. At most two cards are open at the same time. If you click a new card, the one of the two cards that you have opened the longest ago will close again.

- With *image memory*, a match is made by two cards that represent the **same object**. So the images are different, but the object they represent is the same, e.g. a car. Each match gives you **10 points**.
- With *equation memory* a match is made by two cards that have the **same value of x**. Equations are of the form: $ax=b$, $x+a=b$ or $x-a=b$, where a and b are numbers, e.g. if the equation is $x+2=11$, then x is 9. Each match gives you **16 points**

Each match will give you points. But beware; **each click will cost you 1 point**.



$$x + 2 = 11$$

The other game is a **farm game**. With the farm game you can earn points by sending orders that you fulfilled. Fulfill orders by sowing and harvesting the right crops. Choose your seed by clicking on the button of that seed. You sow seeds by clicking on the fields. After you have clicked *all the fields* the time will start and when the growing time is fulfilled, your crops are ready to harvest. Click on the button with the harvest tool and start harvesting by clicking on the fields. If you have harvested enough flowers and grapes to fulfill an order, click on the order to open it and then click to send it (it will turn green).



Because it takes a while for your crops to grow, *you should turn back to the memory game* to score some more points before you return to harvest your crops. But remember, the longer you wait to harvest your fully grown crops, the bigger the chance they are withered. Also, if your storage is full, no more harvested crops will be added to your storage until you first make some room by sending an order.

Blocks

This experiment will last approximately **75 minutes** including instruction time. There will be 4 blocks of 15 minutes each. Between the blocks you can take a short break if you want.

Each block is different. Sometimes you only have to play one of the two kinds of memory. And sometimes you have to play memory and the farm game by switching between them. So after you have sowed some seed you can return to play memory and when you think the crops are fully grown you return to the farm game to harvest them. The order of the blocks will be random, just follow the instructions on the screen.

Practice

Before the experiment starts you can practice a while. Click the buttons on top of the screen to try out all three games. Your score does not matter in the practice round. When you understand the games and know how to use the buttons you can click a button to start the experiment.

If you have any question, feel free to ask!

Good luck at maximizing your score!