The Effects of Mental Workload and Interface Design on Physical Movement

by

Sainjeev Srikantha

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved November 2018 by the
Graduate Supervisory Committee:

Robert Gray, Chair
Russell Branaghan
Nancy Cooke

ARIZONA STATE UNIVERSITY

December 2018

ABSTRACT

Interface design has a large impact on the usability of a system, and the addition of multitasking only makes these systems more difficult to use. Information processing, mental workload, and interface design are determining factors that impact the performance of usability, and therefore interface design needs to be more adapted to users undergoing a high mental workload. This study examines how a primary task, visual tracking, is affected by a secondary task, memory. Findings show that a high mental workload effects reaction time and memory performance on layouts with a high index of difficulty. Further research should analyze the effects of manipulating target size and distance apart independently from manipulating the index of difficulty on performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The research question being investigated in this paper is whether or not mental workload effects physical performance within HCI. Findings can be used to offer interface design suggestions for situations of high mental workload.

The landscape of the Department of Defense (DOD) has changed drastically with the advent of technology. To make the tasks of the DOD easier Joint Terminal Attack Controller's (JTAC) and operators have been outfitted with smartphones and tablets for tactical use to connect with other tactical technologies, and streamline communication and location tracking (Kaul, Makaya, Das, Shur, & Samtani, 2011). These devices for JTACs are used to map out the surrounding area, determine the location of the enemy and their squadron, relay location information to air command, and then disperse this information with your squadron simultaneously (Bragg, 2008). JTACs and other operators within the DOD constantly perform visual tracking tasks within situations of high mental workload, requiring them to utilize multiple resources of perception, cognition, and response type (Bragg, 2008).

High mental workload within HCI can be seen in everyday tasks such as driving. A study researching driving patterns within 100 drivers showed that 78% of crashes and 65% of near crashes involved driver inattention, and in-vehicle infotainment systems accounted for 25% of all events (Klauer et al, 2006). The increase of in-vehicle infotainment systems (navigation systems, media players, smartphones, etc.) have raised concern of driver distraction and roadway safety (Kaber, Liang, Zhang, Rogers & Gangakhedkar, 2012). Between the years of 2014-2015 distraction related driver fatalities rose 8.8 percent increasing from 3,197 to 3,477 ("2015 Motor Vehicle Crashes: Overview", 2016). The amount of mental overload and underload have the potential to negatively affect performance of HCI tasks (Xie and Salvendy, 2000).

HCI improvement can be achieved by understanding user needs through evaluating and comparing interfaces, and developing interfaces and interaction techniques (Sinha, Shahi, & Shankar, 2010). When users interact with systems they utilize their sensorimotor modalities to process multiple types of information at the same time (Wickens 1984, Wickens 2002). When the demand for resources needed for a task increase, and the user does not have the ability to meet these needs, users enter high mental workload (Moray 1979). Performing more difficult tasks require increased mental resource, and when one task requires more of these mental resources the original task is left with fewer mental resources to spare (Norman & Bobrow, 1975). This means that the more resources that are needed for simultaneous tasks increase the amount of a user's mental workload, which can sacrifice task performance.

To further investigate the effects of mental workload on reaction time and accuracy performance Chapter 2 will cover background information of how Fitts's Law is used to predict movement, different models of workload, multiple resource theory models, and how mental workload is measured. Chapter 3 will cover research goals and hypotheses. Experimental design and methods will be discussed in Chapters 4, and experimental results will follow in Chapter 5. Discussion of how findings can be applied to interface design, and general discussion and future research suggestions will be presented in Chapter 6.

CHAPTER 2

BACKGROUND LITERATURE

2.1 Fitts's Law

Fitts's law is a model which predicts a user's movement time in relation to the amplitude of movement and the width of a target (Fitts, 1954; Jagacinski & Flach, 2003). The model has been used in ergonomic psychology and has been used extensively within HCI. It has design applications in interface design and interface evaluation (Mackenzie, 1992). The model has been used to design pop-up menus and has been used in conjunction with ergonomics for smartphone interface design. An important finding from Fitts's law is index of difficulty. The index of difficulty for a system is measured by calculating the $Log_2(2A/W)$, in which A is the amplitude of movement from start to the center of a target, and W is the width of the target (Card et al., 1983). The distance of the target may affect movement time, and the size of target may affect accuracy. For example, an interface that requires users to click a button that is larger and closer to the user will result in faster movement times and be more accurate than a system with a button that is smaller and farther away. Measuring the index of difficulty is significant, because it allows interface designers to analyze the effectiveness or difficulty of different layouts and their target sizes (Card et al., 1983).

Fitts's law allows us to accurately predict rapid aimed movements for pointing tasks, or tasks that require target acquisition. Although this is a helpful theory, there are some other factors that Fitts's law does not take into consideration. For example, it does not consider system response time, mental workload, and modes of selection within various HCI interfaces (Mackenzie, 1992). Coupling Fitts's law with mental resource models to measure mental workload will reveal how a user's movement is affected by high mental workload.

2.2.1 Timeline Model of Workload

The timeline model of workload is the ratio of the time required (TR) to complete a task to the total amount of time available (TA) for task completion (Hendy et al., 1997). The TR/TA ratio is compared to a timeline of tasks that need to be performed, and the amount of time taken to complete that task (Parks & Boucek, 1989; Kirwan & Ainsworth, 1992). Constructing a timeline of tasks is usually done through an observed task analysis, which is the method of observing users and collecting, classifying, and interpreting user performance and needs during a given task (Kirwan & Ainsworth, 1992). The timeline model of workload allows for the prediction of workload users experience and the limits at which performance begins to drop due to overload. User performance drops significantly from overload when TR/TA= 1.0, and when designing HCI it is recommended that TR/TA is less than 0.8 to allow for an excess resource in case users are overloaded (Parks & Boucek, 1989; Kirwan & Ainsworth, 1992).

Problems begin to arise when considering time as the only resource for workload. The first problem is identifying the tasks involved and the time they take. As mentioned before, tasks are identified through observation and recording, and can also be provided by a workload analyst or an expert within the subject of interest (Sarno & Wickens, 1995). The problem with this is that observations do not give us the entirety of the tasks users complete. Covert tasks, such as planning, diagnosis, rehearsing, and monitoring can be overlooked, and these tasks are significant sources of workload. The next problem is automation. When a user becomes proficient at a task they tend to automate certain processes of a task. If a user can automate one or two tasks at the same time or in succession there will be very little overload. The final issue is that certain tasks have competing stimuli, and task overload can occur when a task demands similar or different resources (Wickens 2002). Task demand of resources versus available resources are considered within the resource model of workload and is better at predicting workload when there are overlapping resources (Sarno & Wickens 1995, Wickens 2002).

2.2.2 Resource Model of Workload

The resource model of workload is used to measure mental workload because it takes into consideration user's ability to automate tasks as well as covert tasks. Mental workload is the relationship of the resources required to the resources available. Time is considered a resource, but it is not the only one. The reason for this is that a task could be time consuming but not demanding, and some tasks require an abundance of effort but do not require much time. Coloring in a picture may not require much effort but it may take a lot of time and typing out something that is written on paper may not require much time can still be effortful in having to look back and forth while typing. Analyzing mental workload by assessing the component tasks can be used to create predictive models of workload, and can be used to create a usability analysis of a system. Multiple resource theories and the four-dimensional multiple resource model are used to determine how interference of competing resources drive mental workload (Wickens, 2002).

Multiple resource theories offer two important, practical and theoretical, explanations regarding how resources are used when completing multiple tasks. The first is the practical implementation which allows multiple resource theories to be used to understand user's performance of multiple tasks high mental workload, and the second is theoretical in which performance of multiple resources to predict dual task interference levels between simultaneous tasks (Wickens, 2002). Using the two approaches gives us user information which can be analyzed and coded to create better HCI experiences. As mentioned previously, resources are limited, and are allocated when needed to meet task demands. The resources that are left over are called residual resources, and are used for other tasks, and if a task requires more resources it will interfere with the concurrent tasks (Wickens, 2002). Resources are modality dependent, and previous research has found that dual task performance is poorer when two visual tasks are shared at the same time rather than if one of the tasks are presented auditorily (Treisman and Davies, 1973). A meta-analysis of multiple task experiments conducted by Wickens found that these separate resources are defined and associated with neurophysiological mechanisms which could define how resources are allocated (Wickens 1980). This can be further explained by Wickens' four-dimensional multiple resource theory (Wickens, 2002).

To account for the for the variance within the timeline model of multiple resource theory the four-dimensional model was created. The model is based on four important categorical dimensions which include the processing stage, processing codes, perceptual modalities, and visual channels (Wickens, 2002). Each dimension indicates how there are different resources available depending on the stimuli presented, cognition required, and response type as shown in Figure 1.

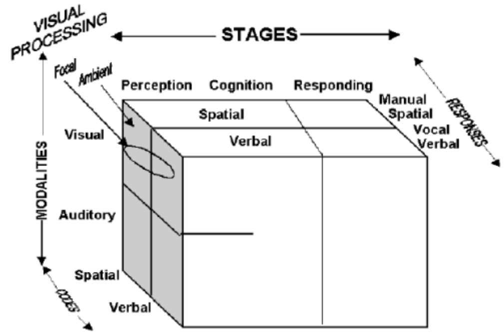


Fig.1: Four-Dimensional Resource Theory (Wickens, 2002)

The stages of processing theory states that perceptual and cognitive tasks use different resources depending on the selection and execution of response (Isreal, Chesney, Wickens, & Donchin, 1980). The way information is presented, spatially or verbally, also determines which resources are used. The codes processing dimension shows that spatial activity and verbal/linguistic activity use different resources stemming from perception, working memory, and action (Baddeley, 1986; Liu & Wickens, 1992; Wickens & Liu, 1988). The last dimension to be added was the different aspects of visual processing, focal and ambient vision (Leibowitz & Post, 1982; Previc, 1998). Focal vision supports how we use vison for object detection, perception for reading tasks, and symbol detection. Ambient vision refers to our peripheral vision, and is responsible for orientation and movement (Horrey, Wickens, & Consalus, 2006).

Mental workload is defined by the demand imposed on people's limited mental resource (Moray, 1979). The demand of resources on users can be broken down into two regions. The first is when the demand of resources is less than the available amount, which means a user is not overworked. The second is when the demand exceed capacity causing performance to suffer (Wickens & Hollands, 2000). From this we can conclude that mental workload can be measured by performance of dual tasks.

2.2.3 Measuring Mental Workload

Through the explanation of multiple resource models, mental workload can be measured by performing two tasks simultaneously. The first task is the primary task, in which users are asked to perform to the best of their ability, and then a secondary task is introduced to probe the users' residual resources. Primary tasks are slowly made harder over time until secondary task performance decreases, which indicates a user is undergoing high mental workload. Some examples of secondary tasks are time estimation, tracking tasks, memory tasks, mental arithmetic, and reaction time tasks (Tsang & Wilson, 1997). The dual task method has a high face validity due to the reasonable measure of demands caused by the primary task (Raby & Wickens, 1994).

CHAPTER 3

HYPOTHESES & STUDY OVERVIEW

The goal for this research is to study the effects of mental workload on physical movement within human computer interaction, and to see whether interface design has an impact on performance. In order to test this a dual task experiment was performed in order to test mental workload. The first task is a visual tracking task, and the secondary task is a visual memory task. The two hypotheses are as stated 1) As mental workload increases, primary task performance will decrease due to an increase in secondary task resources , and 2) Targets with smaller sizes and shorter distances apart will result in better secondary task performance. These hypotheses are based on the findings from the four-dimensional resource model. Both primary and secondary tasks will have competing visual stimuli and draw from the same focal visual resource. With the secondary task demanding more resources the primary task performance will suffer. Although the visual primary and secondary tasks will have competing stimuli, targets with smaller sizes and shorter distances away will allow for the user to see both stimuli within their focal vision. This would allow for less information processing than with targets of larger sizes and farther distances apart.

CHAPTER 4

METHODS

4.1 Experiment Design

The goal of the first part of the experiment is to introduce the primary visual tracking task, and measure reaction time without any memory tasks. The visual tracking task will require participants to click on targets of different sizes and distances apart. Targets are visually presented one at a time. Layouts will include nine targets, and each layout has their own target size and distance with an index difficulty of either 2 or 4. Four layouts will be used for a one-way repeated measures factorial design with four levels, 2.1, 2.2, 2.3, and 2.4. (Table 1) Reaction time in seconds was measured by the amount of time in seconds it takes for a participant to click a target.

The second half of the experiment introduces a secondary memory task. The memory task has two levels, and a 2-way within subject factorial design was used with two levels of memory, memorizing three or six numbers, and four levels for layouts 2.1, 2.2, 4.1, 4.2. (Table 1). Memory tasks for each trial will be different. Reaction time in seconds it takes for a participant to click a target, and memory performance is measured by a correct response to a multiple-choice question.

Layout	**2.1**	**2.2**	**4.1**	**4.2**
Index of Difficulty	2	2	4	4
Target Size	105 pixels	30 pixels	21 pixels	30 pixels
Target Distance	315 pixels	45 pixels	315 pixels	225 pixels

Table1 Layout Title, Index of Difficulty, Target Size, and Target Distance

4.2 Materials

Using Google's user experience interface guidelines as a reference the target sizes used were 21, 30, and 105 pixels (Appendix A). Although the interface guidelines recommended target sizes no smaller than 24x24 pixels and 8 pixels apart, a target size of 21 pixels was chosen to simulate increased difficulty within the visual tracking task ("Spacing methods"). The vector prototyping tool Axure was used to create the targets, and the experiment was hosted and administered online using Qualtrics. The visual memory task asked participants to remember either a set of three or six numbers that are visually placed above each target. Targets are visually presented one at a time, using custom JavaScript within Qualtrics, and show the next target with a click/touch interaction from the participant.

4.3 Procedure

Participants obtain access to the experiment through an anonymous Qualtrics link. Once participants have clicked the link they are greeted with a brief description of the tasks that will be performed and the general length of the experiment. Participants then read through a consent form informing the participant that no harm will come to them from this experiment, and that they are able to exit the experiment at any time if they wish (Appendix B). An online signature is captured to show participants acknowledgement of their consent. The participants read through the instructions for the first half of the experiment, watch a tutorial video of the actions they need to complete, and perform a practice trial. Participants are then asked to perform the first half of the experiment, which consists of four blocks. Each block will contain four trials consisting of a layout of nine targets. A total of 144 targets are presented per participant (Table 2). Between each block, participants are allowed a 1 -2-minute break if needed.

At the end of the first four blocks the participant will be given an intermission, and a forced one-minute break. After the intermission participants are presented with the instructions for the second half of the experiment, a tutorial video, and a practice trial. This part of the experiment introduces the secondary memory task. The second half of the experiment includes eight blocks which each contain four trials of layouts with nine targets. A total of 288 targets are presented to the participant (Table 3). At the end of each trial participants are prompted with a multiple-choice question of the numbers they were asked to memorize throughout the nine targets in the trial. After each block participants are allowed a 1-2-minute break. Upon completing the final block of the experiment participants are asked to answer a demographics survey asking their age range, gender, hand used to complete the experiment, form factor used, and method of input. The trials in each block, and each block are randomized to maintain internal validity.

Experiment (Part 1)	
Block 1	
Layout 2.1	Layout 2.2
Layout 4.1	Layout 4.2
Block 2	
Layout 2.1	Layout 2.2
Layout 4.1	Layout 4.2
Block 3	
Layout 2.1	Layout 2.2
Layout 4.1	Layout 4.2
Block 4	
Layout 2.1	Layout 2.2
Layout 4.1	Layout 4.2

Table 2. Experiment Design Part 1

Experiment (Part 2)	
Block 1	
Layout 2.1, Memory Level 3	Layout 4.2, Memory Level 3
Layout 2.1, Memory Level 6	Layout 4.2, Memory Level 6
Block 2	
Layout 2.2, Memory Level 3	Layout 4.1, Memory Level 3
Layout 2.2, Memory Level 6	Layout 4.1, Memory Level 6
Block 3	
Layout 2.1, Memory Level 3	Layout 4.2, Memory Level 3
Layout 2.1, Memory Level 6	Layout 4.2, Memory Level 6
Block 4	
Layout 2.2, Memory Level 3	Layout 4.1, Memory Level 3
Layout 2.2, Memory Level 6	Layout 4.1, Memory Level 6
Block 5	
Layout 2.1, Memory Level 3	Layout 4.2, Memory Level 3
Layout 2.1, Memory Level 3	Layout 4.2, Memory Level 6
Block 6	
Layout 2.2, Memory Level 3	Layout 4.2, Memory Level 3
Layout 2.2, Memory Level 6	Layout 4.2, Memory Level 6
Block 7	
Layout 2.1, Memory Level 3	Layout 4.1, Memory Level 3
Layout 2.1, Memory Level 6	Layout 4.1, Memory Level 6
Block 8	
Layout 2.2, Memory Level 3	Layout 4.2, Memory Level 3
Layout 2.2, Memory Level 6	Layout 4.2, Memory Level 6

Table 3. Experiment Design Part 2

4.4 Participants

The participants recruited for this experiment were from Arizona State University's Psychology Research Participation Sona System, students from the HSE program, and through social media. Students recruited through the Sona System were given 1 credit of research, and those from the HSE program received extra credit. Participants who were recruited through social media participated voluntarily.

These participants included 8 males and 13 females, with five participants within the 20-25 age range, ten within the 25-30 range, and six who were 30 years or older. Participants were given the choice to use their hand of preference, their method of input, and the form factor of how they took the experiment. Although there is a chance of reducing external validity with unmoderated remote testing, the aim of this study is to see how participants behave naturally with their own preference and how inducing a high mental workload effects reaction time (Calder, Philips, Tybout, 1982). Seven participants used a mouse, thirteen participants used a laptop trackpad, and one participant used touch as a method of input. Seventeen participants used screen sizes 12-17 inches across, and four participants used a display that was 17 inches or larger. All participants are right handed.

CHAPTER 5

ANALYSIS AND FINDINGS

To examine how memory level effected reaction time between the different layouts a 3x4 Analysis of Variance (ANOVA) was performed to test mean difference and interactions between memory levels and layouts on reaction time.

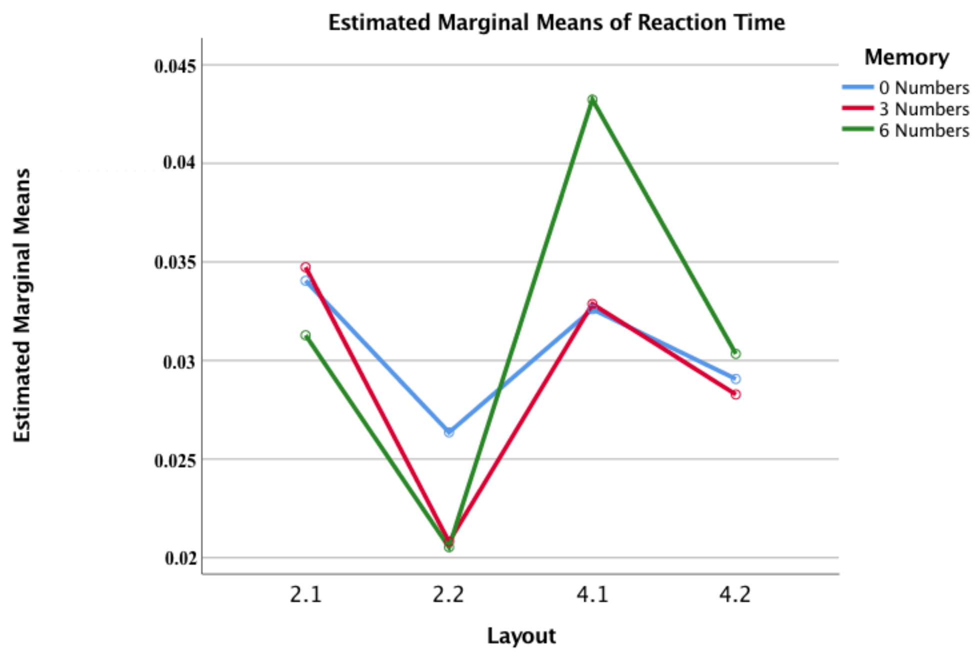


Figure 2. Memory Level and Layout Effects on Reaction Time

Figure 2 shows that the 3x4 ANOVA performed on these data revealed significant main effects of memory level [F(2,1448)=7.602, p=0.001] and layout type [F(3,2172)=14.993, p=0.00]. The main effect of memory level occurred, because, as expected, reaction time was higher when the memory level was higher in layouts 4.1 and 4.2. Alternatively, layouts 2.2 and 2.1 have lower reaction times in the presence of a high memory level. The main effect of layout type occurred, because, as expected, reaction time increased as index of difficulty increased from 2 to 4 between layouts 2.2 and 4.1, and 2.2 and 4.2. However, these main effects were qualified by a significant memory level x layout type interaction [$F(6,4344)=11.089$, $p=0.00$]. This interaction occurred because the difference in reaction time between memory level and layout type were significantly larger between layouts 2.2 and 4.1, and between layouts 2.2 and 4.2.

A paired t-test was performed on the data set to find any simple main effects between memory level and reaction time for layouts of increased reaction time in the presence of a high memory level. The analysis performed shows that there was a significant effect between a memory level of zero numbers and a memory level of six numbers for layout 4.1, $t(739)=-4.543$, $p=0.00$, layout 4.2, $t(745)=-3.431$, $p=0.001$, layout 2.1, $t(744)=2.742$, $p=0.006$, and layout 2.2, $t(724)=7.15$, $p=0.00$. This main effect shows that reaction time under memory level 6 did not affect layouts 2.1 and 2.2.

A second paired T-test was performed to find any main effects between layouts of the same index of difficulty (Table 6). The performed paired T-Test shows that there is a significant effect between layouts 2.1 and 2.2 and 4.1 and 4.2. Reaction time was longer when targets were farther away exposing the relationship between target distance and reaction time.

To examine how memory level affected memory performance between the different layouts a secondary 2x4 ANOVA was conducted to test for mean difference and interactions between memory level and layouts on memory performance.

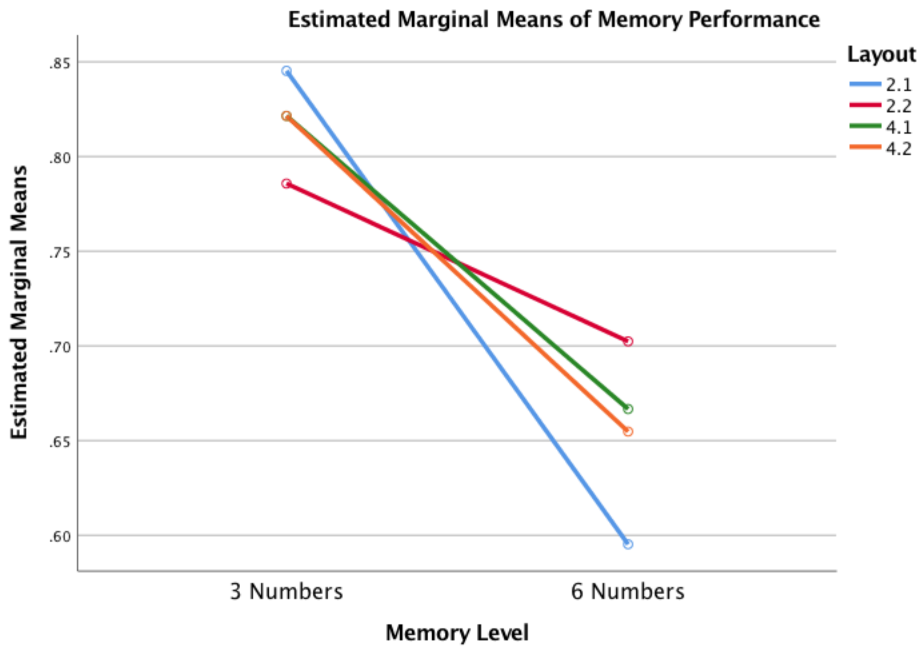


Figure 3. Memory Level and Layout Effects on Memory Performance

Figure 3 shows that the 2x4 ANOVA conducted revealed significant main effects of memory [F(1,83)=21.2, p=0.00]. The main effect of memory level occurred, because memory performance was higher within the 3-number group and lower within the 6-number group. There was no significant main effect for layout, however both factors were qualified by a significant memory and layout interaction [F(3,249)=10.191, p=0.00]. This interaction occurred because the difference in memory performance between layout and memory level have a higher performance for layouts with the lower memory level and a lower performance for layouts with the higher memory level.

A paired t-test was conducted to find the main effects between layout and memory level on memory performance. The paired t-test performed on the data revealed that memory performance was significantly different between memory level in layout

2.1, $t(83) = 5.26$, $p=0.00$, layout 2.2, $t(83)=2.747$, $p=0.007$, layout 4.1, $t(83)=3.898$, $p=0.00$, and layout 4.2, $t(83)=4.074$, $p=0.00$.

CHAPTER 6

GENERAL DISCUSSION

From the analysis on the data sets it can be seen that a high mental workload was achieved by the increase of reaction time in layouts 4.1 and 4.2. This supports that we can accept the alternative hypothesis that reaction time will increase as memory level increases. According to Tsang and Wilson, the decrease in performance on the primary task means participants were under a high mental workload (Tsang & Wilson, 1997). However, a high mental workload was not observed for layouts 2.1 and 2.2, which had lower reaction times with the introduction of the secondary task. Comparatively, there was a significant effect for reaction time between layouts of the same index of difficulty under the same memory levels. This shows that although layouts had the same index of difficulty, reaction time was longer when targets were farther away. The analysis shows that even though layout 4.2 had a larger target size than 4.1, layout 4.2 had a shorter reaction time than layout 4.1 which has a larger target distance. Fitt's law is able to explain this phenomenon as target distance is used to measure reaction time and target size is used to measure accuracy (Card et al., 1983). Layout 2.1, which has a longer target distance than layout 2.2, also had a significantly larger reaction time than layout 2.2. However, this cannot be explained purely on target distance since layout 2.1 also has a larger target size than layout 2.2.

The analysis on the effect's memory level and layout on memory performance showed an interaction between the two variables on memory performance. Further analysis shows that there was no significance between memory level and layout. All layouts had a significantly lower memory performance while performing memory level 6 tasks. Findings show support to accept the null hypothesis of targets with smaller sizes and shorter distances apart will not have a higher memory performance. Although this was true layout 2.2 had the best performance under a high mental workload with the smallest target size and smallest distance apart.

The findings of memory performance also help to further explain the findings for reaction time. Layout 2.1 has the lowest performance for memory level 6 tasks, and also had significantly faster reaction time for memory level 6 tasks than at zero memory level. This infers that at the higher memory level participants focused more of their attention on the primary task rather than the secondary task. Comparing the findings from layout 2.1 and 4.1 it can also be inferred that competing resources from larger targets and a visual memory task caused a shift in attention and a decrease in memory performance. Layouts 2.1 and 4.1 both have the same distance apart and different target sizes, however layout 4.1 did not experience the same shift in attention from both tasks to solely the primary task as can be seen by the increased reaction time for the primary task while also completing the secondary task.

This suggests that further research should focus on the effects of target size on visual object mental resources when paired with a visual memory task. As seen within layout 2.1 and 4.1, there seems to be a shift of attention once a target has reached a certain size. This should be done by analyzing the effects of manipulating target size and distance apart independently from index of difficulty in order to see how reaction time and memory performance are affected.

REFERENCES

2015 Motor Vehicle Crashes: Overview. (2016, August). Retrieved from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318U.S Department of Transportation National Highway Traffic Safety Administration

Baddeley, A.D. (1986). Working memory. Oxford, UK: Clarendon.

Bragg, M. J. (2008). Joint Terminal Attack Controller, A Primary MOS For The Future. doi:10.21236/ada510314

Calder, B. J., Phillips, L. W., & Tybout, A. M. (1982). The Concept of External Validity. *Journal of Consumer Research, 9*(3), 240. doi:10.1086/208920

Card, S., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interactions.* Hillsdale, NJ: Erlbaum.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology,* 47, 381-391.

Hendy, K. C., Liao, J., & Milgram, P. (1997). Combining Time and Intensity Effects in Assessing Operator Information-Processing Load. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 39*(1), 30-47. doi:10.1518/001872097778940597

Horrey, W. J., Wickens, C. D., & Consalus, K. P. (2006). Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. Journal of Experimental Psychology: Applied, 12(2), 67–86.

Isreal, J., Chesney, G., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for a multiple capacity view of attention. Psychophysiology, 17, 259–273

Jagacinski, R. J., & Flach, J. M. (2003). *Control theory for humans.* Mahwah, NJ: Erlbaum

Kaber, D. B., Liang, Y., Zhang, Y., Rogers, M. L., & Gangakhedkar, S. (2012). Driver performance effects of simultaneous visual and cognitive distraction and adaptation behavior. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(5), 491-501. doi:10.1016/j.trf.2012.05.004

Kaul, V., Makaya, C., Das, S., Shur, D., & Samtani, S. (2011). On the adaptation of commercial smartphones to tactical environments. *2011 - MILCOM 2011 Military Communications Conference*. doi:10.1109/milcom.2011.6127649

Kirwan, B., & Ainsworth, L. K. (eds.) (1992). *A guide to task analysis*. London: Taylor & Francis

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data. *PsycEXTRA Dataset*. doi:10.1037/e729262011-001

Leibowitz, H., & Post, R. (1982). The two modes of processing concept and some implications. In J. Beck (Ed.), Organization and representation in perception (pp. 343–363). Hillsdale, NJ: Erlbaum.

Liu, Y., & Wickens, C. D. (1992). Visual scanning with or without spatial uncertainty and divided and selective attention. Acta Psychologica, 79, 131–153.

Mackenzie, I. S. (1992). Fitts Law as a Research and Design Tool in Human-Computer Interaction. *Human–Computer Interaction, 7*(1), 91-139. doi:10.1207/s15327051hci0701_3

Moray, N. (1979). Mental workload: Its theory and measurement. New York: Plenum
Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7*(1), 44-64. doi:10.1016/0010-0285(75)90004-3

Parks, D. L., & Boucek, G. P. (1989). Workload Prediction, Diagnosis, and Continuing Challenges. *Applications of Human Performance Models to System Design*, 47-63. doi:10.1007/978-1-4757-9244-7_4

Previc, F. H. (1998). The neuropsychology of 3-D space. Psychological Bulletin, 124, 123–164.

Raby, M., & Wickens, C. D. (1994). Strategic workload management and decision biases in aviation. *International Journal of Aviation Psychology*, 4(3), 211-240.

Sarno, K. J., & Wickens, C. D. (1995). The role of multiple resources in predicting time-sharing efficiency: An evaluation of three workload models in a multiple task setting. *International Journal of Aviation Psychology*, 5(1), 107-130.

Sinha, G., Shahi, R., & Shankar, M. (2010). Human Computer Interaction. *2010 3rd International Conference on Emerging Trends in Engineering and Technology*. doi:10.1109/icetet.2010.85

Spacing methods. (n.d.). Retrieved from https://material.io/design/layout/spacing-methods.html#containers-aspect-ratios

Treisman, A. and Davies, A. 1973, Divided attention to eye and ear, in S. Kornblum (ed.), Attention and Performance IV (New York: Academic Press).

Tsang, P., & Wilson, G. (1997). Mental Workload. In G. Salvendy (Ed.). *Handbook of Human Factors*. NY: John Wiley.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (eds.), *Varieties of attention* (pp. 63-101). New York: Academic Press.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomic Science*, 3(2), 159-177.

Wickens, C. D. 1980, The structure of attentional resources, in R. Nickerson (ed.), Attention and Performance VIII (Hillsdale, NJ: Lawrence Erlbaum), 239-257.

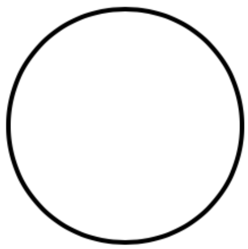
Wickens, C. D., & Hollands, J. G. (2000). Engineering psychology and human performance (3rd ed.). Upper Saddle River, NJ: Prentice Hall

Wickens, C. D., & Liu, Y. (1988). Codes and modalities in multiple resources: A success and a qualification. Human Factors, 30, 599–616.

Xie, B., and G. Salvendy. 2000. “Review and Reappraisal of Modelling and Predicting Mental Workload in Single and Multi-Task Environments.” Work and Stress 14 (1): 74–99.

APPENDIX A

TARGET LAYOUTS



Layout 2.1

Layout 2.2

Layout 4.1

Layout 4.2

The following targets represent the target size for the corresponding layout number.

APPENDIX B

INFORMED CONSENT FORM

Consent Form: Social Behavioral

Title of research study: Psychophysical evaluation performance on user interface design

Investigator:

Dr. Bing Wu, Assistant Professor in Dept. of Human Systems Engineering, Ira A. Fulton Schools of Engineering, Arizona State University.

Why am I being invited to take part in a research study?

We invite you to take part in a research study because you (1) are at least 18 years of age, (2) are NOT pregnant (if female), and (3) have normal or corrected-to-normal vision and no physical/mental disorders.

Why is this research being done?

Enormous amounts of research have been devoted to mental workload and ways to minimalize workload when completing tasks. However, far less research has been conducted on how workload affects physical reaction time, and whether user interface design could affect physical reaction time during high or low mental workload. How these factors influence user's performance will be examined in this study. We aim to gain better understanding of the perceptual and motor processes involved with physical performance and mental workload.

How long will the research last?

We expect that individuals will spend about 1 hour participating in the proposed activities.

How many people will be studied?

We expect about 200 people will participate in this research study.

What happens if I say yes, I want to be in this research?

You are free to decide whether you wish to participate in this study. If you decide not to participate, there will be NO penalty to you, and you will NOT lose any benefits or rights to which you are entitled. If you agree to be in this study, you will be asked to sign this consent form.

The study will be conducted online using Arizona State University's Sona System to recruit research participants. The experimental devices used will be an internet connected laptop or computer to access the experiment, and a tracking mouse of your choice for input. Using the mouse, you will be asked to control the cursor, move the cursor to a target on the computer screen, and then click it. You will be asked to perform these tasks as quickly and accurately as possible. The response time and accuracy of your movements will be recorded. During and after the experiment, you will also be asked to complete a short questionnaire to report your subjective experience.

You will receive 1 course credit for your participation.

What happens if I say yes, but I change my mind later?

Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. Refusal to participate or withdrawal of your consent or discontinued participation in the study will NOT result in any penalty or loss of benefits or rights to which you might otherwise be entitled.

Is there any way being in this study could be bad for me?

There are no known risks from taking part in this study.

Will being in this study help me in any way?

We cannot promise any direct benefits to you or others from your taking part in this research. Your participation will help us to better understand the perceptual and motor processes involved in the gesture-based human-computer interaction. Such knowledge can be applied to the development of more efficient and natural interfacing technology.

What happens to the information collected for the research?

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, your data and consent form will be kept separate. Your consent form will be stored in a locked cabinet in Dr. Bing Wu's office (Santa Catalina Hall 150E) and will not be disclosed to third parties. Computerized data files will be encrypted. Paper data files will be kept in locked locations accessible only to authorized researchers. Your name, address, contact information and other direct personal identifiers in your consent form will NOT be mentioned in any publication or dissemination of the research data and/or results. In this study, you will be assigned a case number and your identity on all research records will be indicated only by that number. We will NOT collect or save any information that may associate that number with your identity.
Efforts will be made to limit the use and disclosure of your personal information, including research study records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your

information include the University board that reviews research.

Who can I talk to?

If you have questions, concerns, or complaints, please talk to Bing Wu, Ph.D.
Dept. of Human Systems Engineering Ira A. Fulton Schools of Engineering Arizona State University
Santa Catalina Hall, Room 150E 7271 E. Sonoran Arroyo Mall Mesa, AZ 85212
(412) 256-8168
(Bing.Wu@asu.edu)

This research has been reviewed and approved by the Social Behavioral IRB. You may talk to them at (480) 965-6788 or by email at research.integrity@asu.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Your signature documents your permission to take part in this research.

This is the informed consent form all participants are required to read and sign prior to beginning the experiment.

32

32