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Eye-Tracking Evaluation of Age-Related Differences in User Behaviour on Mobile Applications

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Abstract: **India is placed as fastest growing countries in the world. In response to the rapid population growth, it is essential to understand the factors affecting ageing population in human-computer interaction (HCI). The usage of smartphones and tablet devices have been increasing rapidly with multi-touch interaction and powerful configuration. Though number of research studies done to analyze user behaviour, they are not adequately focused on aging population as potential users. In India, majority of the smartphone users never used older technologies and they are directly exposed to newer technologies and interfaces. In this context, we have conducted eye-tracking study with 50 participants between the age of 20 to 60 above and living in Bangalore, India. The inclusion criteria followed in our study include literacy and android phone users. The study aims at age-related differences in user behaviour while performing tasks on mobile applications. The study consists of five tasks to be performed on the android phone under naturalistic scenarios by each participant, wearing eye tracking glasses. The activities were recorded for each participant all five tasks. The results our study show differences in the information search behaviours among different age groups. Also, we noted that the tasks that were familiar to aging participants reported better performance and unfamiliar tasks were perceived as complex and unsuccessful.**

Index Terms: **Eye-Tracking Evaluation, Age-Related Differences, User Behaviour, Usability Evaluation, Eye-Tracking Analysis, Mobile Applications, Task Analysis, User Interaction.**

I. INTRODUCTION

Population ageing is an important emerging demographic phenomenon in the world today. The introduction of smart technology has impacted aging population in terms of accessibility and utilization (William & Murugesh 2016). As the society is progressively moving towards digital, the challenges of smart computing and interaction design continue to evolve (William & Murugesh 2016). The social support system is going through a transformation, android phones have become an enabling factor among the aging population to remain connected with family and friends and expand their social network (William & Murugesh, 2018)

The study of human-machine interaction and how they can effectively help humans to achieve optimal task performance in goal-driven situations remain challenging (William & Murugesh, 2018). On one side, the limitation of working memory and attention in the human information system frequently lowers task performance when information becomes immense. On the other side that machines do not have the same cognitive ability as humans to comprehend human needs. In the context of interaction between human and machine, human and computer or human and mobile device, understanding task status is a key factor pursuing goals. As the machines play passive role, it is challenging to engage human performance when humans are taxed by task difficulties. Therefore, it is very essential to understand aging user behaviour for designing intuitive user interfaces.

The present eye tracking study examined the feasibility of wearable eye tracking as an innovative and substantially automated technique for assessing age-related differences in user behaviours while performing tasks on mobile applications. The

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experiment was conducted with 50 participants in an uncontrolled environment in Bangalore, India using wearable eye tracker. This work aims to assist designers to develop intuitive mobile interface for aging users.

Understanding user interaction and behaviour is the most important aspect of user experience. The analysis helps to find users engagement on a screen and methodologies users make to achieve their goal. User interaction and behaviour analysis is done based on the observation of each participant while they were performing tasks. The metrics, we investigated are input mechanism (fingers used), holding pattern of mobile phone and steps followed to accomplish each task. In the input mechanism, the number of fingers used for entering data or select an option or interact with control buttons on the screen are analyzed. Holding pattern of mobile by participants is to analyze how participants hold the mobile and user information to optimize the interaction. There are many ways of doing a task on mobile phone. Analysis of the steps followed by different groups may provide the mental model of user interaction in a specific context.

II. LITERATURE STUDY

Eye tracking the processing power computing enabled real-time video processing in the early 1980s. In 1981, researcher Bolt proposed the first application of eye gaze as interaction method for computers. Later in 1982, Bolt published paper on the importance of gaze for communication and suggests for gaze-awareness for the interface. An important work by Jacob titled "What You Look at Is What You Get: Eye Movement-based Interaction Techniques" was focused on the interactions needed to operate a GUI (graphic user interface) with the eyes. In 1995, Jacob researched on eye tracking in advanced interface design where he emphasizes significance of gaze interaction.

Research shows that there are two areas applications for eye gaze studies (Jacob & Karn, 2003; Duchowski, 2007). Firstly, interaction application to look at eye gaze as a pointing device to select menu by just looking at it. So the accuracy of gaze is very important. Secondly, diagnostic applications, where in cognitive information is derived from the eye movement in specific tasks. In general, most of the existing studies evaluated the effect of age on PCs. Fukuda & Bubb (2003) conducted an eye tracking study to find the difficulties between elderly people and younger people when browsing web pages on PCs. The results showed that the elderly people have issues in using online timetables using PC compared to younger people. Elderly participants took more time than the younger people to complete the given tasks (Fukuda & Bubb, 2003).

Few research studies have analyzed the effect of age on usability of smart mobile phones. Rogers et al. (2005) performed an experiment to evaluate task demands and user age influence of task performance on touch screen devices and non-touch screen devices with 40 younger participants, aged between 18–28 years old and 40 middle-aged to older participants, aged 51–65 years old. In this study, control tasks like sliders, up/down buttons, list boxes and text boxes were used. The outcome of their study showed that the older participants were slower than younger participants on performing tasks such as pointing and sliding. Also, they found small size buttons were problematic for older participants. Al- Showarah et al. (2013) conducted an experiment to assess the eye movements of elderly and young participants and to find dissimilarities in browsing on different smartphone/tablet applications. The study revealed that the elderly people were less efficient in browsing smartphone applications/interfaces than younger people.

Older adult's relationship with technology is a valuable area for research and has been studied significantly in the past. The use of technology tends to decrease with age (Selwyn, 2004). In general, older people use only few technologies than younger people and use them less frequently (Carroll et al., 2017). Older people with cognitive issues may perceive technology as more challenging to use (Rosenberg et al., 2009) and people with higher cognitive levels are expected to participate in a wide-ranging web-based tasks (Freese et al., 2006.). Perceptual speed, the domain of cognitive ability, has been found to be a sensible predictor of determining desktop browsing characteristics in older adults (Crabb & Hanson, 2016).

In summary, we observed that though there several research studies carried out in the past using eye tracking techniques, mostly, they are limited to smaller number of participants. Also, we noted that a smaller number of studies carried out on mobile applications. Our study consists of wide variety of user groups performing five different real-time tasks on an android mobile phone. We used wearable eye tracking glasses to record eye activities and analyze the ageing user behaviour.

III. RESEARCH METHODOLOGY

The study was designed to evaluate age-related differences in user behaviour on mobile applications using eye-tracking techniques. We recruited 50 participants out of 180 participants including 25 males and 25 females, aged 20 to over 60 years old (Joseph et al., 2021). Short Portable Mental Status Questionnaire (SPMSQ) was used to evaluate the mental status of participants (Pfeiffer, 1975). Additionally, eye information was also considered to select participants who are comfortable with near vision and could read mobile screen with eye-tracking glasses without any difficulties.

Participants were grouped into five groups: Group-A (20-29 years), Group-B (30-39 years), Group-C (40-49 years), Group-D (50-59 years) and Group-E (60 year and above). Each group had 10 participants and the oldest participant was 77 years old. The inclusion criteria included were literacy, usage of android phone and residing in Bengaluru City (Joseph et al., 2021).

Samsung Galaxy S7 Edge smart phone with octa core (2.3 GHz, Quad core, M1 Mongoose + 1.6 GHz, Quad core, Cortex A53) processor was used for performing tasks. It works on

Samsung Exynos 8 Octa 8890 Chipset with 4 GB RAM and 32 GB internal storage (Joseph et al., 2021). For recording eye activity, Tobii Pro Glasses with a sampling rate of 100Hz was used. Tobii Pro Lab was used to analyze visual information.

The participants were asked to perform a set of five tasks on an android mobile phone. The tasks were designed based on the essential requirements for fulfilling daily activities on android mobile phone. For each task, task scenario and task flow were given to contextualize the experiment (Joseph et al., 2021). After completing all tasks, subjective interview was conducted with each of the participant. The objective of this experiment was to understand how ageing affect user experience on the android mobile.

IV. Results and Discussion

Understanding user interaction and behaviour is the most important aspect of user experience. The analysis helps to find users engagement on a screen and methodologies users make to achieve their goal. User interaction and behaviour analysis is done based on the observation of each participant while they were performing tasks.

The results and discussion of the eye-tracking analysis research study are centered on the five tasks performed on the android mobile phone. Before the test, each participant was given enough time to familiarize with the interface of the Samsung Galaxy S7 Edge phone. For the analysis we have taken the parameters of time taken to perform each task and visualization of heat map using attention filter (Joseph & Murugesh, 2020). Additionally, we investigated metrics such as input mechanism (fingers used), holding pattern of mobile phone and steps followed to accomplish each task. In the input mechanism, the number of fingers used for entering data or select an option or interact with control buttons on the screen were analyzed. Holding pattern of mobile phone was analyzed to understand how participants hold the mobile and use information to optimize the interaction. Finally, the analysis of steps followed to accomplish the task was carried out to understand the mental model of user interaction in a specific context of task performance. The task-wise results are discussed below.

The participants were grouped into different age groups such as 20-29, 30-39, 40-49, 50-59 and 60 above and the results were analyzed accordingly. The goal was to find patterns among different age groups co-relate them with task performed in order to understand how ageing affect user experience on android mobile. It was observed that 64% of the participants were holding bachelor's degree, 28% of the participants were holding master's degree, 4% of the participants completed pre-university course (PUC) and 4% of the participants were holding Secondary School Leaving Certificate.

A. *Task-1: Adding Phone Number to Contact*

Adding a phone number to contact was the first task, performed by all participants. The task scenario was that "*you have met your schoolmate Kishore Kumar after a long time, and he has shared his new mobile number with you and add his new mobile number to contact list*". It was considered as a simple task. All participants successfully completed the task, but time taken to complete the task differed as shown in the Fig. 1. The effect of ageing clearly shows the incremental change in the time taken to perform the given task. The Group-A (20-29) participants required a less time and Group-E (60 above) required four times more than the younger participant to complete the task.

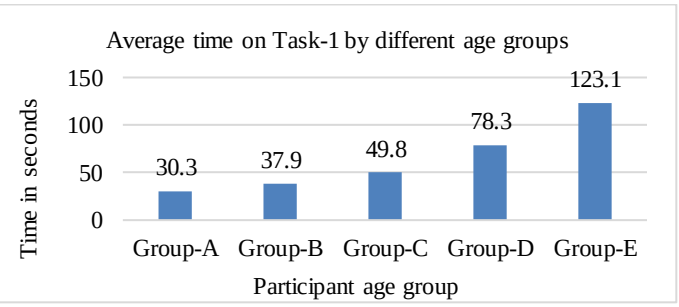

Fig. 1. Average time taken to complete Task-1

The visualization of heat map, as shown in the Fig. 2, effectively illustrates the focus of the visual attention on the Task-1 and indicates the looking behaviour of all participants in relation to the Task-1. All age groups had a misunderstanding whether to use Phone App or Contact App for adding the contact details. Group-A and Group-B added the contact by creating new contact, enter name and phone number which is the normal process one should ideally follow. On the contrary Group-C, Group-D and Group-E followed their own method of adding the contact to the contact app. They dialed the number and disconnected the call abruptly to add the number to the contact app. Among all participants, the Group-E, struggled to find the create new contact option and spent more time on find the right option which was clearly mapped by the heatmap shown in the Fig. 2.

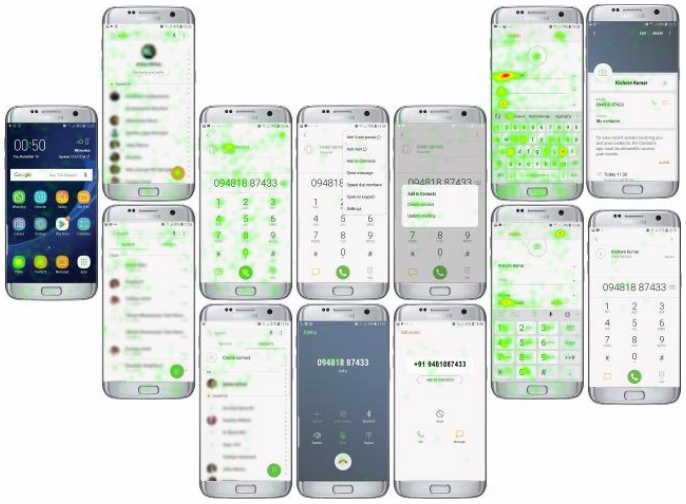

Fig. 2. Heat map visualization of Task-1

The holding pattern of mobile phone varied among different age groups. Younger participants were holding mobile with both hand and older participants were either holding it with left hand or positioned it on the table and interacted with the mobile. We observed that younger participants used right and left thumb for input and interaction with interface elements but for older participants right thumb, right index finger and right middle fingers were used.

B. Task-2: Sending Birthday SMS Greeting

The second task (Task 2) performed by all participants was sending birthday SMS greetings to a friend (Kishore Kumar). The task scenario was "*It is your friend's birthday today and you have decided to send a greeting to him, consisting of text and emotive via SMS'.* In comparison to Task-1, this task (Task-2) was found

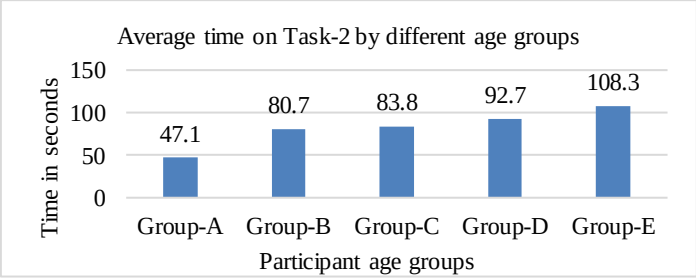

Fig. 3. Average time taken to complete Task-2

incrementally little difficult. Except for one participant, the remaining were able to successfully complete the mission, but time taken to complete the task different for each group of participants as shown in the Fig. 3. Here too, there is a substantial evidence that younger participants required less time to complete the task and as age progresses, the older participants required more time to complete the task. It amounts to twice as the younger participants to perform the task by the elderly participants.

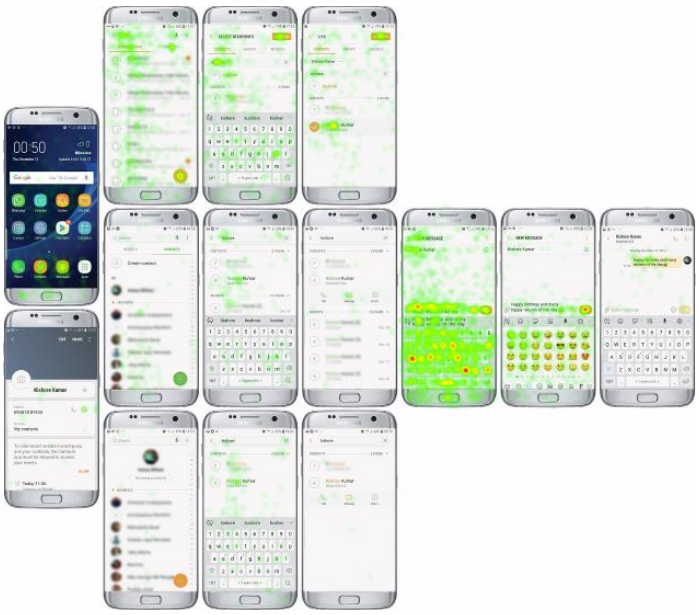

Fig. 4. Heat map visualization of Task-2

The visualization of heat map (Fig. 4) confirmed that there was a trend towards increase in the eye fixations among participants in relation to the Task-2 performed. Younger participants completed the task by following five steps and elderly participants took more than five steps. Similar to Task-1 performance, Group-A and Group-B and Group-C in Task-2 were able to compose the message without any difficulty but Group-D and Group-E took more time and effort to compose the full message "*Happy Birthday and many happy returns of the day*".

As age increases, the task performance was slowed down, and more time was spent on composing the given message. Also, we noted that the elderly struggled to find the right option and were finding difficult to understand the user interface elements on the screen to accomplish the task. The participants' interaction behaviour on the mobile phone with respect to the Task-2 performed shows that the holding pattern was very similar to the Task-1 among different age groups.

Right and left thumbs were very active for input text and interacting with interface during the task performance. As the age increases, right index finger became very active for all interactions. As people age, hand function decreases and age-related changes in grip and pinch strength and hand dexterity in the elderly pose a greater challenge on the touch-based mobile interface (Carmeli, 2003).

It was very interesting to notice, that all age group participants used suggestive tool tip while composing the message. While the individual was given the task outline, the ageing participants often struggled to identify options at a given point in time. The younger participants composed full birthday message as given "*Happy Birthday and many happy returns of the day*" but most of the older participants composed only the minimum message "*Happy Birthday*" The second task showed a reasonable increase in time and number of steps taken to complete the task across age groups as compared with task one. Observation showed the interface was not intuitive and there was a struggle and multiple attempts to carry out the task as age increases.

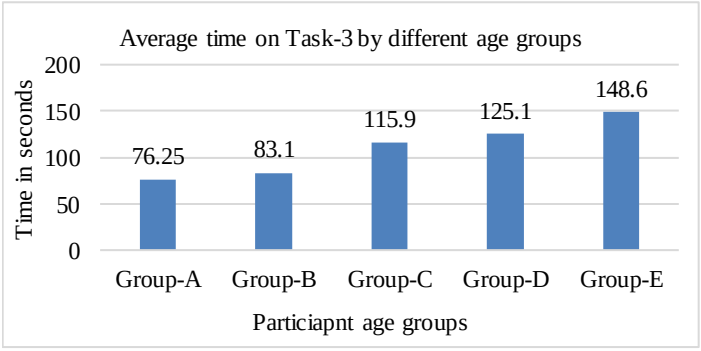

Fig. 5. Average time taken to complete Task-3

C. Task-3: Google Search and Save Information in Memo App

The third task (Task-3) performed by all participants was Google search and save information in Memo App. The Task-3 scenario was to "*You are reading a novel and you have come across a new vocabulary concomitant in your storyline. You do*

not understand the meaning of the word and you have decided to look into google search, find the meaning and save it in the Memo app." Of all the five tasks, this task (Task-3) was the most challenging.

Fig. 6. Heat map visualization of Task-3

The Task-3 was complex with respect to activities inside the task, such as searching Google, copying text, opening Memo App, past text and saving. There were sixteen participants, belonging to Group-C, Group-D and Group-E were unable to complete this task and the other thirty-four participants had completed the task with success. Remarkably, Group-D and Group-E recorded the lowest performance due to complexity and task within tasks. Fig. 5 shows that the time taken to complete Task-3 was very high in comparison to all other tasks.

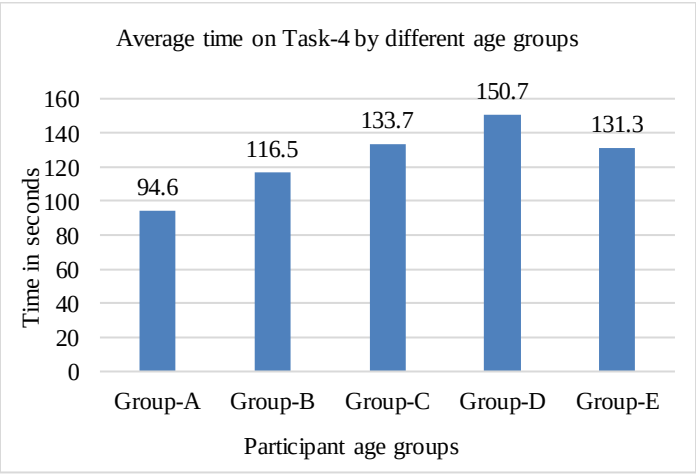

Fig. 7. Average time taken to complete Task-4

The visualization of heat map as shown in the Fig. 6 shows a substantial evidence that the attention of ageing participants was on the Google search page and the activities followed thereafter. It provides information that participants spent more time on the Google search page which includes select and copy action required to save the information in Memo app. The interaction behaviour of participants on the mobile phone in relation to the task performed provides information regarding holding patterns that were very similar to the other above tasks. Right index finger, right and left thumbs and right middle fingers were used for input text and interacting with control buttons. Younger participants used their thumbs very actively, but older participants used their right index finger and right middle finger actively for their interaction.

Participants of Group-A and Group-B successfully performed the task, Group-C reasonably performed and for Group-D and Group-E, it was a major hurdle to complete the task. They were struggling to find options copy and paste and made multiple attempts by trying various means and interaction but failed. We noticed that it created a stressful situation among the elderly participants and majority ended unsuccessfully. This task had, many sub tasks within the main task and it demanded many steps from the participant.

D. Task 4: Online Shopping using Amazon App

Online shopping using Amazon app was the fourth task performed by all participants. The scenario for Task-4 was "*Your cousin's birthday is next week, and you wanted to give him a 7-inch tablet computer as a surprise birthday gift. Your budget limit for this gift is Rs. 12000/- only. Select the gift from amazon app and add to the shopping cart*". This task was the second most difficult task in comparison to the Task-3. Over all 39 participants completed the task successfully but 11 participants could not complete the task due to complexity of the task and other user interface factors. Younger age group performed well, and the older participants had problem in terms of identifying the right

Fig. 8. Heat map visualization of Task-4

product, searching, selecting and sorting during the task which increased task on time. The Fig. 7 shows that participants were

taking more time in terms of find the right product and make a decision. Group-D and Group-E spent more time in finding the desired product on the Amazon App. The heat map analysis of the Task-4 indicates attention area of the participants and it is primarily focused find the right product within the given budget. The Fig. 8 indicates that greater amounts of time was spent on searching and find the right product and the activities followed thereafter. The major issue found in this task was that participants of Group-B, Group-C, Group-D and Group-E could not find the '*add to cart'* button instead pressed the shopping cart icon which is on the right top of the Amazon App.

The interaction behaviour of participants while performing the Task-4 shows that the holding pattern of mobile was very similar to the previous tasks. For input and interacting with control buttons were also observed as similar to previous tasks. The majority of participants used auto suggestion technique while searching for product. There were two major issues found by the participants were finding the right product and adding to the cart. Older participants were making multiple attempts to get the right option, but the interface did not behave, the way they wanted.

We found that one of the participants tried to zoom in on the screen, but this never happened. In the second problem the mental model mismatch with respect to the shopping cart was clearly linked. Participant tried multiple times to add the desired product to the shopping cart by clicking the shopping cart icon but failed to add the product to the cart because the application does not allow the participant to add product in such a way. This happened to the older participants and in general the Task-4 was perceived as complex due to less user-friendly interface elements.

E. Task-5: Sending WhatsApp Message

Sending WhatsApp message was the fifth task performed by all participants. The task scenario was "Your friend is applying for a personal loan in SBI bank and he wants to give your name as reference. He needs your personal particulars information to fill

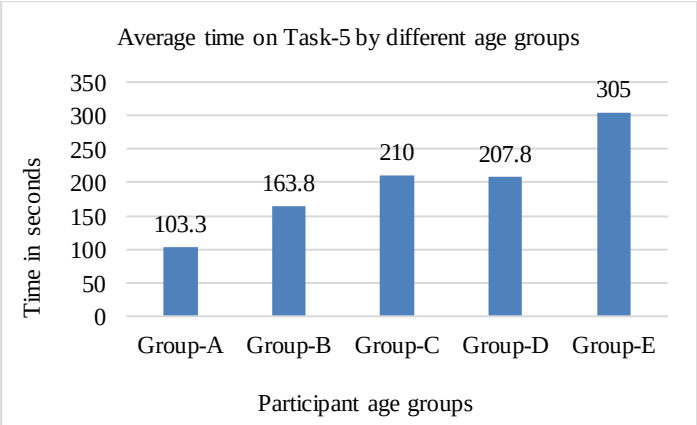

Fig. 9. Average time taken to complete Task-5

up a loan form in the reference section. You have decided to SMS the information. Send the required information to him and he is waiting in the bank to complete the procedure".

As this task involved personal information, we have requested each participant not to give their real information. This task was the third difficult task and this task demanded more texting. Except two, the rest of 48 participants completed the task

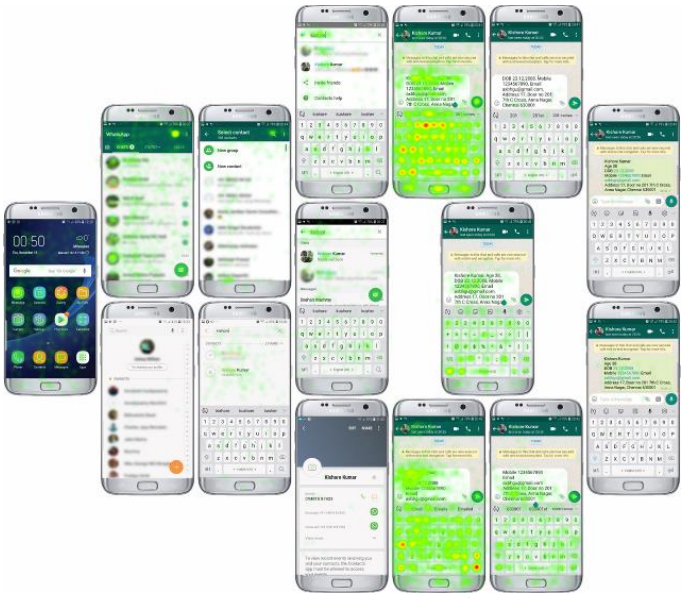

Fig. 10. Heat map visualization of Task-5

successfully. The participants had taken the maximum time for this task as it consisted of textual information. Fig. 9 shows that all participants performed well but maximum time was consumed to accomplish this task due to texting.

Visualization of the heat map shows that older participants spend more time finding the correct contact name and texting the given message as shown in Fig. 10. Participants of Group-A and Group-B opened the WhatsApp, searched for '*Kishore Kumar'*, composed the message and sent but Group-D and Group-E struggled to find the right contact and made multiple attempts, such as searching alphabetically and using the search bar.

The interaction behaviour of all participants during the task is very similar to the previous results. An interesting texting behaviour was noted that the older participants texted the complete message in a paragraph format without separation. A small percentage of younger participants composed the required message in a separate line with all punctuation but majority of the older participants, particularly Group-D and Group-E composed the information in a paragraph format without punctuation due to the limitation visual-spatial aspect of keypad on the mobile interface.

CONCLUSION

This study aims to investigate age-related differences in user behaviour on mobile phone applications using eye tracking techniques. The study was carried out with 50 participants of different age groups (20 to 60 above) using eye tracking glasses and tasks were performed on mobile phone applications. Five tasks were designed, and each participant was asked to undertake

all the five tasks. Bengaluru city was chosen for our study the city has known as IT capital of India and attracted people from across India and abroad.

We examined input methods and user behaviours such as number of and kind of fingers used for input, number of steps followed to accomplish a task and holding pattern. These results were corelated with the eye tracking heatmaps and gaze behaviours. The findings provide insights for user-interface researchers, UI designers and usability analysts to design intuitive user-interface for aging population. The complexity of human behaviour and the strategies users adapt during a task performance exhibited a deep understanding of their interaction behavioural structure. Tasks which were familiar to ageing participants, reported better performance and unfamiliar tasks were perceived as complex and reported unsuccessful. The complexity of the task performance was correlated with ageing. Ageing related issues like decline in sensory motor and cognitive abilities play an important role to understand the user behaviours. One major problem identified was usability issue of ineffective representation of visual elements and that represents the user action. There was a mismatch between user interface elements and users' mental model which led to poor performance of tasks and increased cognitive load.

The task performance was correlated with time taken to complete the task and number of tasks completed successfully and analyzed them with heat map. We found differences in the information search behaviours among different age groups found using the visualization techniques through eye movements. Younger participants were using their right and left thumbs for input and all other interactions but on the contrary the older participants were using predominantly the right index finger and in some occasion they used right middle finger. The elderly participants placed the mobile on the table and were interacting with either right index finger or right middle finger. This shows a low confidence in holding the mobile and performing the task.

There is a major challenge for further studies to address the issues of gender-based factors affecting cognitive load through eye tracking metrics and modeling cognitive load. The work can be further extended to different age groups and identify cognitive factors affecting user experience.

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