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Abstract: While user accesses a user interface, visually searching for a particular object is inevitably accomplished. Visually searching for information, one of the fastest and most useful way of finding information over a variety of user interfaces is driven by different features associated with it. Further, the level of significances of a feature may vary from one interface to another. This paper proposes an exhaustive way to identify visual features associated with virtual keyboard interfaces. First, we list all visual features which user interface designers usually refer. Next, a user-based evolution has been carried out to find out the applicability of different visual features in the context of virtual keyboard interfaces. Finally, we identify visual features having considerable impact on visual search task, related to virtual keyboards. Outcome of this research would be useful to develop a computational model to predict visual search time, which then can be applied to evaluate virtual keyboard designs.

Keywords: visual search; user interface design; virtual keyboard; automatic design; design evaluation; human computer interaction.

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1 Introduction

Of present day technologies, use of computer has been widened and enjoyed by varieties of users in many applications, compared to its previous limited use in scientific research and calculations. As a consequence, interaction styles have been changed from command mode to direct manipulation mode (Raymond and Landley, 2004). With direct manipulation style of interaction, a user can perform any task comfortably as it offers clear visibility of intermediate and final results. While accessing the interface, the main concern of a user turns to visually find proper objects which are required for performing a task. Therefore, for a sighted user, visual search contemplates to be a significant cognitive subtask while performing any kind of task in today's user interface (UI).

Visually searching for information is often fastest and most useful way of finding information in a variety of UIs. Functionalities such as web search or the 'Find' command found in many operating systems can be used to find items on a computer screen quickly. Although, there are many instances in which visual search is more useful, like

a searching an object among many similar objects where it is difficult to specify a search query to locate the desired target (web search results)

b when an application does not include a find command (video games)

c when the exact target is not known (looking for items that match some vague concept or goal), etc.

In these cases, fast eye movements are necessary where many visual objects can be evaluated simultaneously, and target(s) can be located if exists. The visual search process that people use has a substantial effect on the time and likelihood of finding the information they seek. Users encounter many challenges in finding the information they seek while searching visually. In fact, visual search is affected by many factors of the layout such as grouping, colour, spacing, text size, etc. and also strategies used like item-by-item search, using labels or not, following the columns or not, etc. It has been observed from experiments that, intensity of the object feature in an object space often takes the decision of selecting target from the distracters. Distinguishing more number of similar objects in visual search space requires more number of features (Treisman and Gelade, 1980). It becomes a challenge to the UI designers to design an interface which has appeal to all categories of users.

Visual search, core of visual information searching, is a subtask in each and every visualisation-based interaction with computers. So, visual search time required to perform a task plays an important role while evaluating *usability, user friendliness* of an interface. Visual search time of an interface can be measured directly either by user-based evaluation or by a computational model. A computational model would be capable of calculating visual search time from different parameters present in the interface. On the other hand, user-based evaluation requires performing tasks by users with different perceptual and cognitive capabilities on an interface. In user-based evaluation, a large number of users with varieties of profile are needed to be involved which is time consuming, tedious as well as expensive. In contrast, a computational model uses different features to estimate average visual search time and thus provides both time and cost effective solution and also needs less users' effort. It may be considered as UI prototyping tool that can produce quantitative predictions of how users will behave when the prototype is ultimately implemented. It provides a rapid and inexpensive way to explore a large variety of UI ideas, compare them, and narrow down the options to a handful of designs to be empirically tested with users.

Computational cognitive models are necessary to develop any automated interface analysis tool. Projects such as CogTool (John and Salvucci, 2005; Teo and John, 2008) and CORE/X-PRT (Tollinger et al., 2005) are the frontrunners among them. These tools provide theoretically grounded predictions of human performance in a range of tasks without requiring that the analyst (the person using cognitive models) be knowledgeable in cognitive, perceptual, and motored theories embedded in the tool. Designers of interfaces could use such tools to evaluate their visual layouts, reducing the need for user testing, early in the development cycle. A visual search time prediction model useful for specific application has been proposed previously (Hick, 1952; Hyman, 1953), considering only a single feature. So, the challenge still exists for addressing the issues as well as developing a predictive model for computing visual search time for different interfaces.

In digital devices, virtual keyboard is an indigenous tool to compose text efficiently. While composing texts, user needs to search the intended key which is required to click next. Along with the mouse movement and clicking on the button, visually searching for the proper character also contributes significantly in total time required to compose a text. Hick-Hymen law (Hick, 1952; Hyman, 1953) has been offered to quantify visual search time. According to this law, required time depends only on the number of keys present in the keyboard. It has been observed that visual search time varies for different keys and also depends on different features of keyboard layout. The present work proposes to bridge this gap. Objective of our work is to identify other features which also affect visual search time significantly in the context of virtual keyboard interfaces. Here, we have listed all visual features reported in the literatures, analysed their applicability on keyboard interfaces and performed user-based evaluation to recognise influence of individual features. Consequently, a computational model can be built using these identified features, which will be capable to calculate the average visual search time of a virtual keyboard interface more accurately.

The rest of this paper is organised as follows. Section 2 reviews recent literatures on visual search task that are relevant to visual search time modelling. Section 3 presents motivation and objective behind this research. Different visual search features with brief descriptions, referred in various literatures, are listed in Section 4. Sections 5 and 6 concise experimental details behind feature identification in context of virtual keyboard and corresponding results, respectively. Finally, Section 7 concludes this paper.

2 Literature review

In order to create a model of visual search time which is useful to design UI, we must first consider the general premises of such a model. This section provides an overview of relevant literatures on visual search and computational cognitive modelling. A variety of models have been developed to predict visual search behaviour. Some of them are even developed for specific domain, such as graph perception.

Feature integration theory (FIT) states that people shift attention serially from one object to the next, deciding for each whether it is the target or not (Treisman and Gelade, 1980). According to FIT, attention must be directed serially to each stimulus in a display whenever conjunctions of more than one separable feature are needed to distinguish the possible objects presented. It has been assumed that the visual scene is initially coded along a number of separable dimensions, such as colour, orientation, spatial frequency, brightness, direction of movement and features are registered early, automatically, and in parallel across the visual field, while objects are identified separately and only at a later stage, which requires focused attention. This process is said to be necessary when conjunctions of object features (colour, shape, size, orientation, etc.) differentiate targets from distracters, for example, searching for a red X among green X's and red O's (conjunction search). According to FIT, attention is necessary for the correct perception of conjunctions, although unattended features are also perceived next to conscious perception as without any attention. However, these results could also be the result of inefficient parallel search processes. This type of theories are supported by a variety of evidence presented a simple parallel model that reproduced the finding of feature search times independent of number of objects in the search display and conjunction searches times linearly dependent on number of objects.

Guided search (GS) (Wolfe et al., 1989; Wolfe, 1994, 2001) is a computational model of how visual features such as colour and orientation direct visual attention. GS suggests that serial visual search can be guided by information from parallel processes. It predicts that the order in which objects are visually searched is affected by 'strength' of objects' visual features (e.g., their blueness, yellowness, steepness, and shallowness), differences between objects, spatial distance between objects, similarity to the target, and distance of objects from the centre of gaze (i.e., the eccentricity). GS claims that *the parallel processes guide the 'spotlight of attention' towards likely targets*. A similar idea is also claimed by Hoffman (1978, 1979). The proposed idea is a two-stage model where a parallel first stage informs likely targets to a slower and serial second stage. Although the search strategy behind conjunction search, is not explained properly in this model. According to GS model, the serial search cannot use the information collected by parallel search. A serial search cannot exactly identify the location of a conjunction target. It can divide the all items into two sets, one may contain the target and other may not. The information gathered in parallel search, when transferred to serial search, is not perfect due to random noises. So the parallel process might incorrectly guide the spotlight to a distracter rather than to a target. Thus serial search often examines incorrect items.

The area activation model (AAM) (Pomplun et al., 2003) is another computational model which describes how visual features direct visual attention. The basic assumption behind this model is *saccades in visual search tend to foveate display areas that provide a maximum amount of task relevant information for processing during the subsequent fixation*. This model calculates saccadic selectivity, that is, the proportion of saccades directed to each distracter type, by assigning saccadic endpoints to the closest display item. But the possibility that the placement of saccadic endpoints may be guided by the combined relevance of several nearby items is ignored here. This model shares many characteristics with GS, but differs in at least one important way. It assumes that all objects near the centre of gaze are searched in parallel and GS assumes that objects are searched serially.

Understanding cognitive information engineering (UCIE) is a computer model of human reasoning related to graphs and tables (Lohse, 1993). It is based on goals, operators, methods, and selection (GOMS) (John and Kieras, 1996), a model to predict task execution time. The object perceiving time, eye movements, and limited memory for information are constraints for the simulation of scanning of graphs and tables.

Executive process-interactive control (EPIC) is a framework for building computational models of tasks that lends itself well to build models of visual search (Kieras and Meyer, 1997). EPIC provides a set of perceptual, motor, and cognitive constraints based on a variety of psychological literature. Models of visual search built within EPIC explain visual search in view of cognitive strategies as well as perceptual and motor constraints.

3 Scope and objectives

Visually searching for information is omnipresent in all kind of graphical UI related tasks. Visual search time plays a significant role to measure usability of any UI. It helps interface designers to evaluate their design with minimum effort. Most of the reported works are mainly about describing the visual search methodologies. UI designers advocate many visual features to be incorporated in designs so that a user may interact efficiently with the interfaces. Many such visual features have been referred in recent literatures (Clark, 2001; Dosher, 1998; Bond, 1982; Nagy et al., 2005; Neider and Zelinsky, 2006; Everett and Byrne, 2004; Palmer et al., 2000; Herd and O'Reilly, 2005; Goonetilleke et al., 2002; Fleetwood and Byrne, 2006; Näsänen and Ojanpää, 2003; McSorley and Findlay, 2001; Hornof, 2001; Kramer et al., 2006; Byrne et al., 1999). However, model to predict visual search time with respect to visual features is yet to be reported. It may be noted that, as visual search is a vast domain of research, it is very difficult to model visual search time for any visual search task, in general. With growing need of text composition tasks in digital gadgets like PDAs, smartphones, etc., HCI designers are looking for the better design of virtual keyboards. The visual search is an important task in addition to pointer or finger movement. As on date, visual search time to evaluate the efficacy of a virtual keyboard is grossly ignored. The model proposed by Hick (1952) and Hyman (1953) has been used to evaluate virtual keyboard interfaces. But, it only considers total number of keys present in the keyboard. It lacks in acquiring other visual search features like shape, size, grouping, ordering, etc., which, in fact, influence visual search time in finding a character in the keyboard. This work attempts to bridge the said limitation. Main objective of this work is to identify and analyse the features which influence visual search in the context of virtual keyboards.

4 Listing of visual features

We have studied visual features reported in different literatures which influence visual search. Impact of many of these features is subjective to user and beyond the scope of measuring them quantitatively. It is therefore an issue to identify which visual features are user specific and which are quantitatively measurable or analysable. So, from the listed features, we have identified the features whose impact do not vary with user and also relevant in the context of virtual keyboard interface.

Visual search activity is known to be governed by many visual search features. The following visual search features, which UI designers usually refer, are listed below with a brief description of each.

- *Size*: The task of finding an object among distracters differs with the size of the same (Clark, 2001; Bond, 1982). For example, if an interface contains objects of different sizes, then visual search time is not necessarily same for all objects.
- *Shape*: UI designers believe that shape of an object is a factor in visual perception (Clark, 2001; Bond, 1982). When a user searches for an object, it is usually compared with objects in the search space (Barbur et al., 1993; Palmer et al., 2000). In other words, the target objects need to be compared with a set of similar objects, where shape of the objects controls the time of matching.
- *Spacing*: Placing of objects in a design space affects the visual search activity (Everett and Byrne, 2004). It is true that if objects are placed sparsely then it demands a different visual search time than when the objects are placed densely.
- *Orientation*: Orientation of an object influences the visual search task and as a result, visual search time varies with objects' orientation (Clark, 2001). Like, time to find a straight line among straight lines with similar orientation is not same compared to the time to locate the same straight line from a set of straight lines with different orientation.
- *Total number of items*: Usually objects of an interface visible at a time are compared randomly against the target till the target is located (Barbur et al., 1993; Palmer et al., 2000). Thus the total number of items present in a visual search space controls the finding of an object in the search space (Hick, 1952; Hyman, 1953; Hornof, 2001).
- *Number of distracters*: A distracter is an object which is not the target at an instance. So in a visual search space all different items except the target are considered as distracter (Dosher, 1998; Bond, 1982; Herd and O'Reilly, 2005).
- *Types of distracters*: The heterogeneity among distracters like variation by size, shape, orientation, etc., contributes moderately in visual search task (Wolfe, 2001; Bond, 1982; Nagy et al., 2005; Neider and Zelinsky, 2006; Everett and Byrne, 2004; Palmer et al., 2000; Fleetwood and Byrne, 2006; Duncan and Humphreys, 1989).

- *Size of a search field*: UI designers experience that size of a search field is also a factor in visual perception (Clark, 2001; Bond, 1982; Palmer et al., 2000). If an interface have a significant number of items, distributed evenly and visible at an instance then searching for an item usually become random (Wolfe, 1998; Herd and O'Reilly, 2005; Byrne et al., 1999). Although, search time does not solely depend on size of the search space, but also varies in parallel with density of the object within the unit space of the interface (McSorley and Findlay, 2001).
- *Place of a target*: Placing of target in a proper position within an interface often helps user to find it in a short time. Usually, interface designers and psychologists observe that user's focus is more concentrated for some portion or zone of the interface (Pomplun et al., 2003; Kieras and Meyer, 1997; Lohse, 1993). So, finding any objects residing at or around those areas often becomes easy.
- *Ordering*: It has been observed that ordering of objects affect visual search task (Byrne et al., 1999; Anderson et al., 2000). Like, the time required to find an item in an ordered list differs from the time required for an unordered list.
- *Grouping*: In any interface, the object can be found more quickly if it is placed apart from the crowd (Hornof, 2001). Also, it is comparatively easy to find an individual object from a group containing specific feature-based objects rather than from the total interface consisting of several constraints.
- *Size of a group*: Size of a group indicates the number of items or objects in a particular group. Visual search time to locate an object depends on the size of a group (Hick, 1952; Hyman, 1953).
- *Labelling of a group*: Labelling of groups within an interface also helps user to identify them more specifically. As an example, it would be easier to access the virtual keyboard if labelling can be done in each group like vowel group, consonant group, numeric group, etc.
- *Colour of a text and background*: Colour property of an object may influence visual search time of an object. If a target is easily discriminable from its distracter due to colour difference then the search time required to find the target visually become different (Clark, 2001; Bond, 1982).
- *Contrast of a background*: Visual search time is also affected by background contrast. Greater background contrast helps more to identify the target, that is, visual search time becomes lesser. For an example, effort required to read a black coloured text with white background and yellow coloured text with white background is not equal (Nagy et al., 2005; Neider and Zelinsky, 2006; Näsänen and Ojanpää, 2003).
- *Contrast of distracters*: When there is a notable difference in contrast between target and distracters then the time to identify the target differs (Nagy et al., 2005; Neider and Zelinsky, 2006; McSorley and Findlay, 2001). Like, from a set of similar shaped objects, a red coloured object (target) can be easily identified when other objects (distracter) are green coloured.

- *Density of a search item*: The density of items has several aspects like horizontal and vertical distance between the objects, hollowness of the object, etc. It has been reported that visual search time varies with density of search item (Goonetilleke et al., 2002).
- *Ageing and memory*: Older adults face more difficulty than younger adults to identify and locate a target defined by a conjunction of features among heterogeneous distracters (Kramer et al., 2006). It has been observed that with practice, people can learn to find a target from randomised object set almost as quickly as from ordered object set (Hornof, 2001; Byrne et al., 1999).
- *Search strategy*: Visual search time directly depends on the search strategy followed while searching, like top-down searching, bottom-up searching, item-by-item searching, randomised searching, etc., (Clark, 2001; Bond, 1982).

5 Experiments

All visual features not necessarily contribute equally in visual perception (Treisman and Gelade, 1980; Wolfe, 2001). Some features may not be applicable for a particular interface as well as the effect of few features varies from a user to another user. So, to model visual search task, a categorisation of visual features is required. We aim the categorisation with respect to applicability on virtual keyboard interface. Further, the features which may be applicable in virtual keyboard interface design may not influence visual perception equally and also may depend on user. In order to identify the user dependency and influence, several experiments with users have been carried out. Details of the experiments are given below.

5.1 Setup

All experiments have been conducted using 2.4 GHz Pentium Core2Duo machine with a 17" colour monitor with $1,280 \times 1,024$ resolution. The developed interfaces for these experiments are written in C# using Visual Studio 2008. All key press events are recorded automatically and stored in a log file. The mouse positions are also stored in separate log file using a separate window hook programme written in C#. All experiments are done in Windows 7 environment.

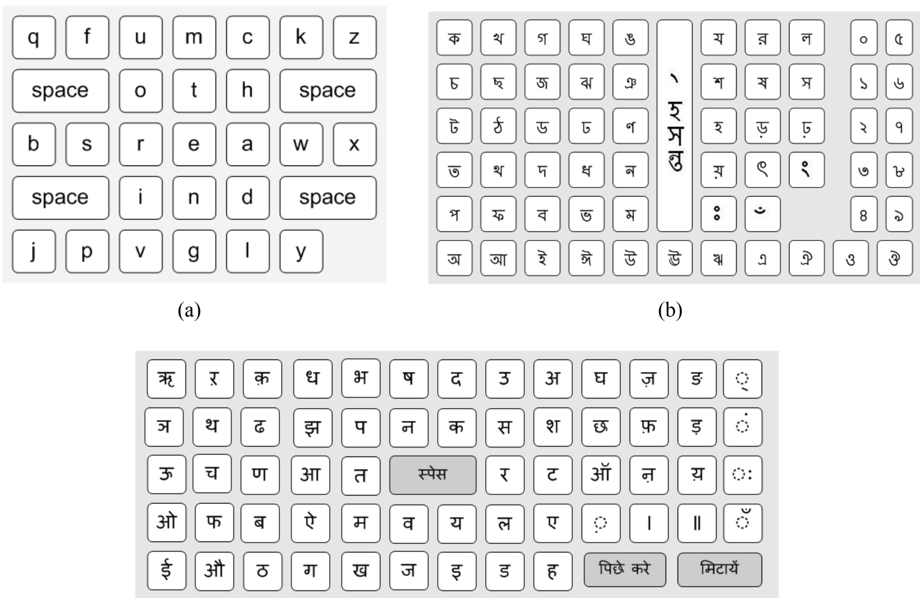
5.2 Interface used

Three virtual keyboard interfaces have been used namely, *Opti*, a virtual keyboard layout for English language (MacKenzie and Zhang, 1999), *Avro*, a virtual keyboard layout for Bengali language developed by OmicronLab (2010) and *iLipi-H*, a virtual keyboard layout for composition of text in Hindi proposed by Samanta et al. (2012). Figure 1 shows the layout of each interface.

- *Opti (a frequency-based keyboard layout)*: It is one of the optimised virtual keyboard layouts for the English language. Figure 1(a) shows the *Opti* layout as described by MacKenzie and Zhang. The keyboard layout was optimised for speed using trial and error, Fitts' law, and bi-gram frequencies of characters.

- *Avro (an alphabetical keyboard layout)*: This keyboard uses the alphabetical arrangement of Bengali alphabets. The consonants are divided into two sub parts, as shown in Figure 1(b). All vowels are present in a row at the bottom of the layout.
- *iLiPi-H (a multizonal, frequency and inflexion window-based keyboard layout)*: In this keyboard layout, Hindi characters are spatially arranged in layered zones depending on their frequencies of occurrences [Figure 1(c)]. The high frequency characters are placed in a central zone, the next higher frequency characters are placed in its outer zone surrounded by the central zone and so on. In addition to this, inflexions are dynamically appeared through an inflexion window for each consonant.

Figure 1 Virtual keyboard layouts used in experiments, (a) *Opti* keyboard layout (b) *Avro* keyboard layout (c) *iLipi-H* keyboard layout



(a) (b)

(c)

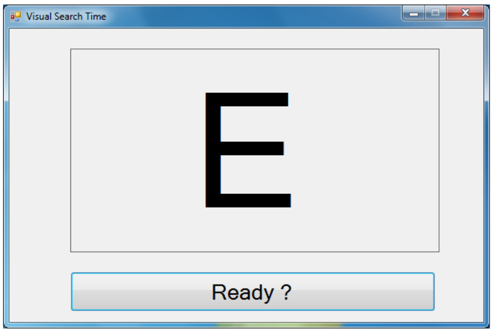
5.3 Participants

To perform the experiments with users, we include 21 total users in our experiments. Depending on their education and familiarity with computers, these users can be classified into two categories: *User* 1 and *User* 2. The users in *User* 1 category are skilled and regular computer users such as higher secondary school, undergraduate students and office stuffs. In *User* 2 category, we include people who are novice computer users, like shopkeepers, primary level school students. For conducting the experiments in three different Indian languages, we select three business persons, four office stuffs and six graduate students in *User* 1 category. We choose two shopkeepers and six school students in *User* 2 category.

5.4 Procedure

In our experiments, four to seven different experimental sessions are carried out by each participant. Each session includes several trials having two parts: stimulus presentation (target) and layout presentation (interface). The goal of each trial is to locate the target within the interface. An experimental trial begins by presenting a target followed by a virtual keyboard interface till the goal is achieved. A sample layout with target is shown in Figure 2. We have used three different fonts namely *Times New Roman*, *Vrinda* and *Mangal* to display English, Bengali and Hindi characters respectively, which remains same throughout all experiments.

Figure 2 A sample layout with target object (see online version for colours)



The target is displayed until the participant either hit the spacebar or clicks the mouse, indicating he/she is ready to proceed. Once the participant is ready, a virtual keyboard interface is displayed. Participants are instructed to either press the spacebar or click the mouse again as soon as they locate the target within the interface. After that, the participant is required to move the mouse to the identified target and click the same. A trial is considered to be finished when these steps are completed. The visual search time of each trial has noted programmatically and stored into log file. Next, a fresh trial is started in the same way with a different target. A session continues till all characters are considered in trials or the participant does not willing to continue further.

The cursor position is programmatically controlled and locked on the initial screen that is where the target is displayed first. Cursor is programmatically kept hidden on the interface until a participant finds the target within the interface, so he/she is not getting distracted by the cursor position. For remaining of a trial, the mouse position has not been controlled. It has been reported that a participant may get acquainted with the interface while accessing over a long time (Wolfe, 1998). This result lesser visual search time compared to the situation where the participant is not familiar with the interface. The difference becomes higher over the time. Although this effect depends solely on user and affects intelligent users mostly, still we have tried to reduce this. In our experiments, the chance of selecting any of the three interfaces for a particular trial is equal.

By analysing the log files, we have calculated the centre value for each variation of a feature and plotted them into graph. Note that both median and mean can be used to calculate the centre value, but median reduces the average of the absolute deviations whereas mean makes it biased towards the extreme value. Hence, we have used median to calculate the centre value. We have also conducted analysis of variance, that is, ANOVA test to study the significance of each feature on visual search time. The ANOVA tests are conducted using *statistical package for the social sciences*, also called SPSS tool (IBM, 2010).

6 Results

We have listed the features which influence visual search. The preliminary analysis of those features reveals that some features are not applicable in the context of virtual keyboard.

Orientation: In a virtual keyboard, orientation of all characters or keys present in the keyboard layout is similar (MacKenzie and Tanaka-Ishii, 2007). So, we should not consider this feature while modelling visual search task in the context of virtual keyboard.

Search strategy: As keyboard contains a large number of keys as well as users get acquainted after accessing the layout for some time, so it is not required for the user to search all keys within the interface following any search strategy. The searching is accomplished in random fashion usually (Wolfe, 1994; Wolfe et al., 1989).

Distracter type: Although, some keys like *backspace*, *enter*, *shift*, etc., are larger in size than other keys in keyboard interface, they do not affect on visual search task significantly. After being familiarise with the keyboard interface, users can find those buttons quickly not because of their different size and shape than distracter, but from their natural tendency (e.g., after certain time, user will guess the buttons correctly from their fixed position) (Wolfe et al., 1989; Wolfe, 1994).

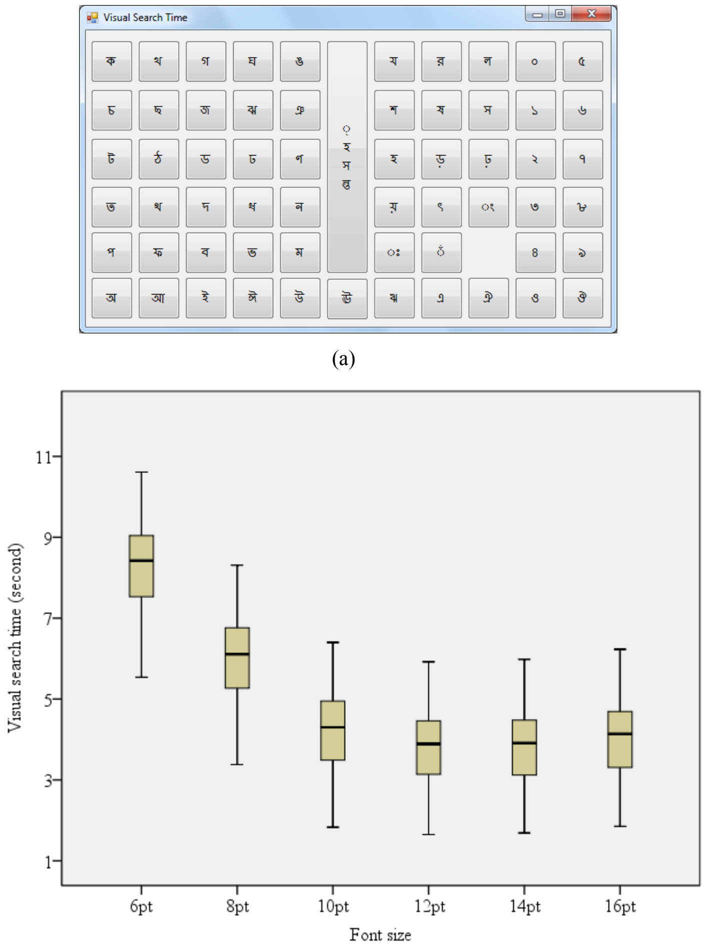
Varying spacing: We have observed that, in a virtual keyboard interface both the horizontal distance and the vertical distance between keys remain same throughout the keyboard layout. The variation of horizontal distance and vertical distance do not consider as a good virtual keyboard design methodology. If varies, the design lacks user comfort.

Colour: While accessing the graphical UI, colour feature retains impression in user's mind. In contrast, the feature behaves differently from user to user. So, the colour choice of background of virtual keyboard, button colour, font colour, etc., may attract one user but may distract another. So, it is unlikely that a particular combination of colours in the keyboard may satisfy all the users.

Thus, the other features like size and shape of the keyboard, spacing between character keys, number of items present in the keyboard, grouping and group size are selected as the features for experiments with users. The results of each experiment are described below.

Size: Size is a primitive property of all kind of objects. So, in a virtual keyboard interface size may refers to size of the entire interface, size of a button or size of the text appears on button, that is, font size of the text. Here, we have focused our experiments on font size and kept other sizes or features unchanged throughout these experiments. A set of experiments to observe the influence of size on visual search time has been performed. For each experiment, a keyboard layout has been chosen, different font sizes have been applied on that keyboard keeping all other features unaltered. The font size is varied from 6pt to 16pt with an increment of $2pt$. From our experiments, we have observed that characters are almost unreadable for font size less than $5pt$, so 6pt is considered as minimum font size. Figure 3(a) shows instance of *Avro* keyboard layout with $12pt$ font size. The analysis of experimental results is shown graphically in Figure 3(b). We have also calculated median of search time for different font sizes and keyboards and observed that visual search time is higher at lower font size. ANOVA test reveals that there is a significant difference between performance of different font sizes $(F_{5,217} = 18.12, p < 0.05)$.

Figure 3 Effects of different font sizes on visual search time, (a) *Avro* keyboard with 12pt font size (b) visual search time for different font size (see online version for colours)



(a)

(b)

Shape: Shape of an object is defined by the geometric properties of the object. In context of virtual keyboard interface, the shape may refer to the virtual keyboard itself, the buttons of the interface or the characters included in the interface. We have limited our experiments only to shape characteristics of the characters. The shape of a character depends on the font used by the system and remains same for a particular font. So, this experiment is designed to find the effect of similar characters on visual search. To achieve this target, first we have identified and grouped the similar character of a language. Here, we have considered Bengali language for our experiments. Table 1 shows the similar character set of Bengali language. Later, when a user is asked to find a character which belongs to a group of that set, one or more characters from that group may present in the interface. We have analysed the experimental results and depicted the same in Figure 4. From the analysis, it has been substantiated that the presence of similar shaped characters in virtual keyboard interface affects visual search time, although the effect is very less. The increment in visual search time due to presence of four similar shaped characters over single character is 4.21%. ANOVA test indicates that there is no significant difference among the performance of similar shape characters on visual search time $(F_{3,94} = 2.301, p > 0.05)$.

Table 1 Similar character set of Bengali language

	Similar characters	*Base character*
Group 1	অ, আ, ত	ত
Group 2	উ, ঊ, ড, ড়	ড
Group 3	এ, ঐ, ঞ	এ
Group 4	ও, ঔ	ও
Group 5	ক, ব, র, ঝ	ব
Group 6	ট, ঢ, ঢ়	ঢ
Group 7	য, য়, ষ	য

Figure 4 Effects of similar shaped characters on visual search time (see online version for colours)

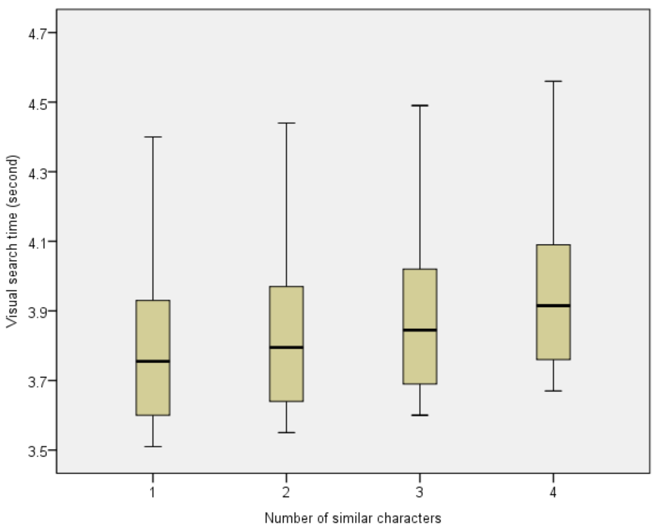
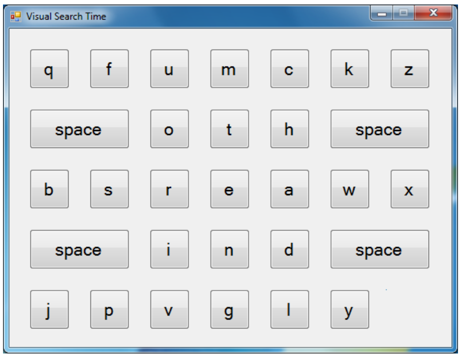
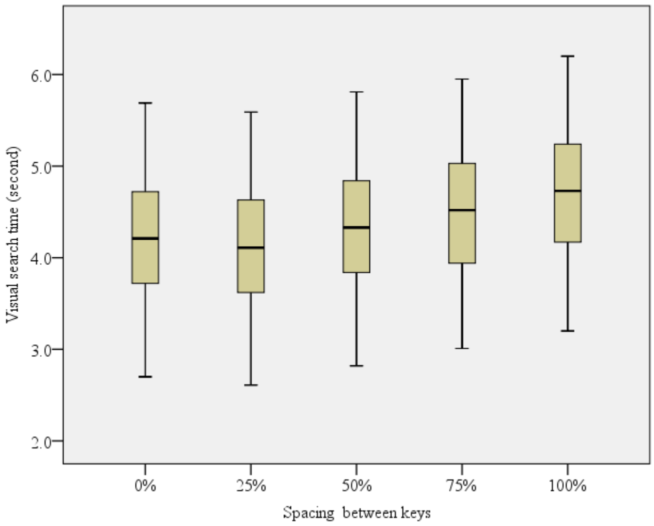


Figure 5 Effects of spacing between keys on visual search time, (a) *Opti* keyboard with 50% spacing between keys (b) visual search time for different spacing between keys (see online version for colours)



(a)

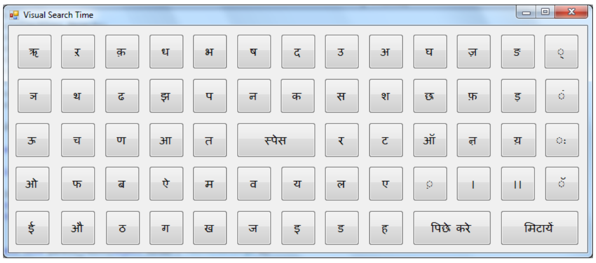


(b)

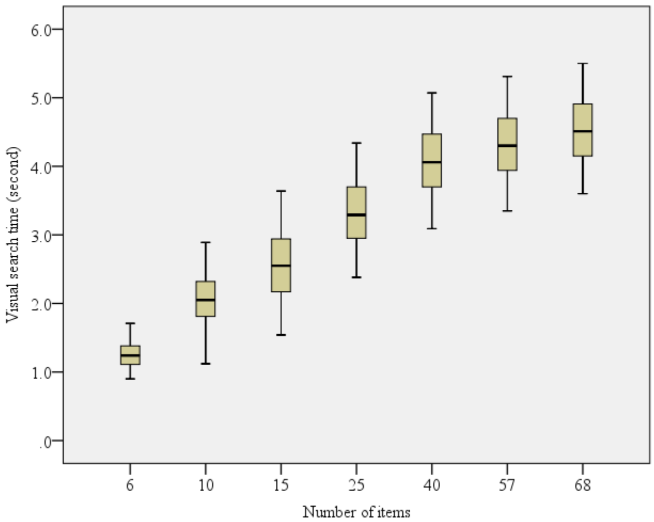
Spacing: Spacing between the keys is also considered as an important visual feature. In context of a virtual keyboard interface, spacing between the keys refers to the horizontal or vertical gap between the key buttons. The experiments are performed on varying space between keys keeping other features constant. Also, for a particular instance, we maintain equal distance between all keys. A set of experiments to observe the influence of spacing on visual search time has been performed. In these experiments, the spacing between the keys is varied from no spacing to 100% of the button width with a step of 25%. Figure 5(a) shows *Opti* keyboard with 50% of button width as spacing between keys. It has been observed that spacing between the keys affects visual search time which can be varied from user to user. From the experiments, we have observed that visual search time is lesser when the distance between two keys is around 25% of the key size. Figure 5(a) depicts results collected from the experiments which are conducted on different conditions on three keyboard interfaces. From the analysis of ANOVA, we have concluded that the mean of performance of users for different spacing are significantly different $(F_{4,205} = 15.643, p < 0.05)$.

Number of items: Many items present in the interface may distract the concentration of user while searching for specific item and as a result, search time increases. To study the effect of number of items present in an interface, the virtual keyboard layouts are required to be modified to have different number of characters. In these experiments, we have considered seven different variations among number of items, that is, $6, 10, 15, 25, 40, 56, 67$. An instance of *iLiPi-H* keyboard with 67 characters is shown in Figure 6(a).

Figure 6 Effects of varying number of items on visual search time, (a) *iLiPi-H* keyboard having 67 items (b) visual search time for different number of items (see online version for colours)



(a)

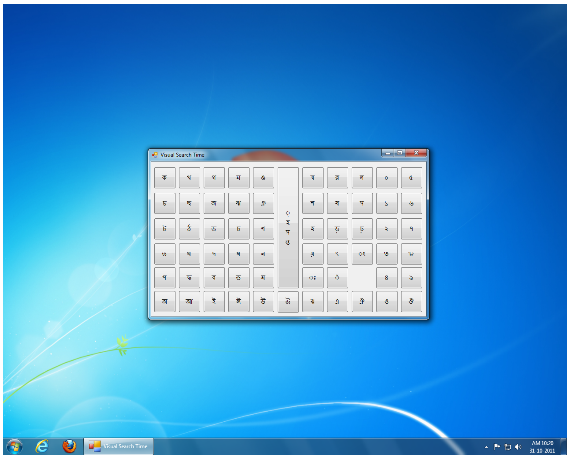


(b)

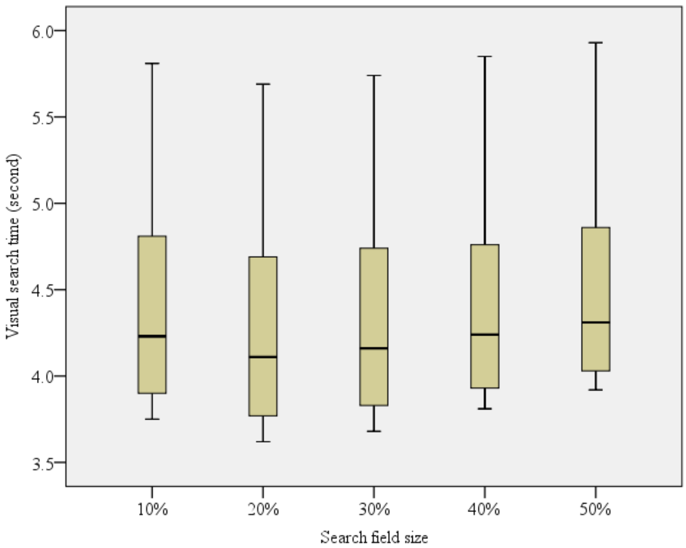
It has been observed that number of items within the interface influences visual search time which can be different from user to user. The analysis reveals that some user efficiently search the item within interface jumbled up with several objects but others may not follow the same trend. As a consequence, the result may vary from user to user for unchanged features except number of items. We have observed that usually visual search time increased with the increasing number of items present in the interfaces. Experimental results in different scenario are plotted in a graph which is shown in Figure 6(b). The ANOVA test reveals that there is a significant difference between the mean of visual search time as determined by different number of items on keyboard $(F_{6,266} = 41.673, p < 0.05)$.

Number of distracter: In any keyboard interface, number of distracters is almost equivalent with number of items present in it. So, no other experiment has been performed, as results would have been similar.

Figure 7 Effects of search field size on visual search time, (a) *Avro* keyboard occupying 20% of screen area (b) visual search time for different search field size (see online version for colours)



(a)

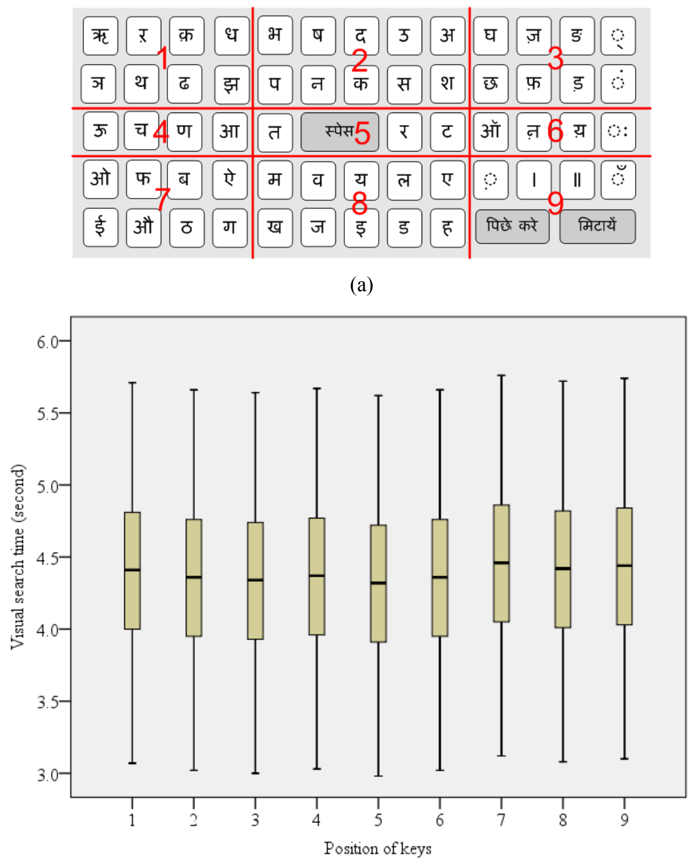


(b)

Search field size: The size of the area where user is intended to search the item may affect the visual search time. To measure the effectiveness of search field size on visual search task, we conduct experiments. In these experiments, search field size, that is, interface size has been varied from 10% to 50% of the screen area with an increment of 10%. *Avro* keyboard occupying 20% of screen is shown in Figure 7(a).

The result signifies that, if all features remain unchanged except search field size, visual search time increases while search field size is less than 20% or greater than 40% of the screen area. Figure 7(b) depicts the results collected from the experiments which are conducted with different screen sizes on three keyboard interfaces. We have performed ANOVA test on visual search time for different search field size. From the analysis we have concluded that the mean of visual search time for different search field size are not significantly different ($F_{4,87} = 2.352, p > 0.05$).

Figure 8 Effects of different position of keys on visual search time, (a) *iLiPi-H* keyboard divided into nine blocks (b) result for different position of keys (see online version for colours)



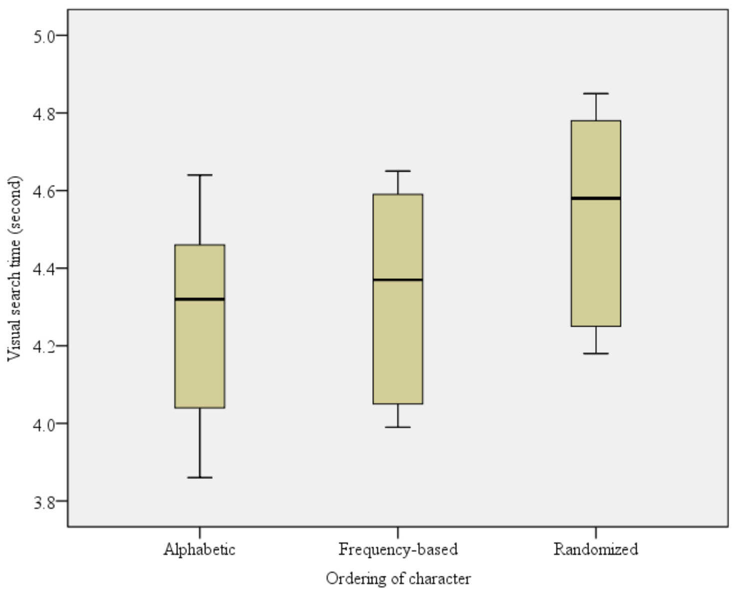
(a)

(b)

Position: Positioning of objects in the interface also influences visual search time. Similarly, in a virtual keyboard interface, different key positions also affect the visual search time. There are 30, 61 and 66 different key positions possible for *Opti*, *Avro*, *iLiPi-H* keyboard interfaces, respectively. As it is not possible to observe the alteration of visual search time for each position and accommodate all the results pictorially, we divide the keyboard layout into nine different blocks as shown in Figure 8(a). We have calculated visual search time for each block and plotted in a graph, shown in Figure 8(b). From the graph, we can observe that visual search time varies for different position of characters. A reported measure analysis of variance reveals that, there is a significant difference between mean of visual search time for nine different blocks $(F_{8,314} = 11.29, p < 0.05)$.

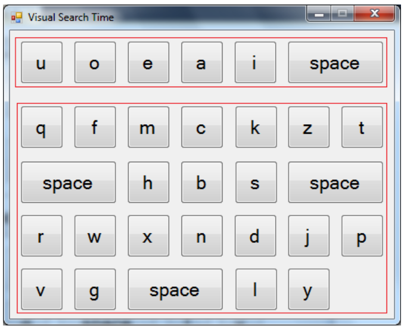
Ordering: Ordering of objects within interface is also considered to be an influential factor in determining visual search time. We have considered alphabetical, frequency-based and random ordering of keys in our experiments. The experimental result establishes the fact that random ordering of the objects results in more searching time than other orientations. We have noticed that different kinds of ordering influence users much in finding keys from the interface. If all features are same, then it has been found that alphabetic arrangement helps a user more in finding a key from the keyboard. The other frequency-based arrangement takes less time than highest-valued random arrangement. The observed effect of these different arrangements of keys on visual search time is shown in Figure 9. The ANOVA test on experimental results reveals that there is a significant difference between the mean of visual search time for different ordering of keys $(F_{2,24} = 28.59, p < 0.05)$.

Figure 9 Effects of ordering of characters on visual search time (see online version for colours)



Grouping and group size: An object can be found out quickly in an interface if it belongs within a particular group of objects and group size is not large. To study the effect of grouping and group size on visual search time, we have modified keyboard layouts maintaining similar type of characters, i.e., consonant, vowel, numeral, etc., in a group. As an effect, the layout contains a maximum of seven groups with varying group size. Figure 10 shows an *Opti* keyboard layout modified to organise characters into two groups with different group size.

Figure 10 *Opti* keyboard with two group (see online version for colours)



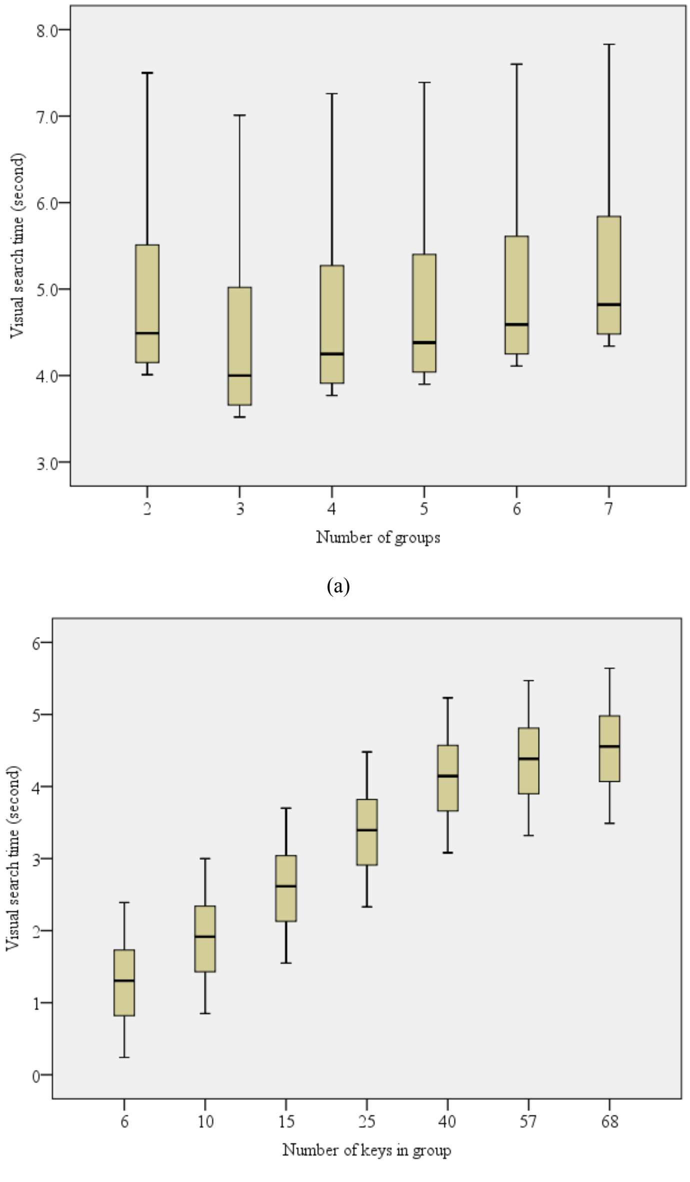
The experimental result establishes the fact that a moderate number of groups, each having a minimum number of objects, facilitate more in obtaining lesser visual search time. The results are graphically depicted in Figures 11(a) and 11(b). ANOVA reveals that, the mean of visual search time as determined for different grouping and group size are not equal. The observed value of ANOVA for different group is $F_{6,30} = 12.49$, $p < 0.05$ and grouping is $F_{6,79} = 27.426, p < 0.05$.

6.1 Observation

We have performed experiments on varying sizes of object. From the result, we can observe the tendency of visual search time growth with respect to different text size and fixed fonts in three different languages. The outcome shows that for all keyboards, visual search time is pretty high for small sized fonts (like 6pt). The visual search time decreases with increasing font size up to a moderate value ($12pt$). But when the size of object is high ($14pt$ or more), the curve corresponding to each language keyboard grows up. It means that, users get acquainted with text size belonging to certain range. Beyond that, the visual search task for finding keys becomes time expensive for human.

From the effect of space between object in a virtual keyboard, it can be observed that visual search time varies significantly with variation of space between object. Visual search time is less when space between objects around 25% of the object size. The number of items in a virtual keyboard also contributes in visual search time and corresponding effect is also significant. We have observed that visual search time gets higher and increases almost linearly when number of items in virtual keyboard raises. On the other hand, proportion of screen area occupied by virtual keyboard does not affect significantly in visual search time. Visual search time is almost constant irrespective of proportion of screen area occupied.

Figure 11 Effects of grouping and group size on visual search time, (a) visual search time for different number of grouping (b) visual search time for varying group size (see online version for colours)



(a)

(b)

We have also found that position and grouping of objects plays vital role in visual search time. The analysis of experimental results and statistical study establish the fact that there are six features, which contribute more in visual search time in the context of virtual keyboard. The features are:

- size of elements
- space between elements
- number of elements
- position of elements
- ordering of elements
- grouping and group size.

The identified features can be further helpful to develop a model which will compute the average visual search time of a virtual keyboard interface.

7 Conclusions

With increasing use of user interacting applications, evaluation of UIs is becoming more important. To evaluate an interface, some issues are needed to be considered. Visual search time is one notable issue among them. Visual search is inevitably proved to be significant point of concern in the context of evaluating specific virtual keyboard interface. Performing user-based evaluation of any UI is a practically tedious job. So, researchers advocate automatic design and evaluation procedure which includes modelling of different performance metrics. The features of virtual keyboard interface which influence visual search task are needed to be identified prior to model visual search time. This work specifically concentrates on performing the same. We have listed the features which influence visual search time. Next, we have performed some experiments of virtual keyboard interfaces with users of different expertise level. From analysis of results of these experiments, we have identified six features which influence visual search task while composing text through the interface. The identified features influence many other cognitive task performed in the context of virtual keyboard. Further, these features would be considered while modelling visual search time for virtual keyboard. Thus, the evaluation of virtual keyboard interfaces will become easier and as a result, automatic evaluation will be more accurate. The future work will focus on collecting data from users by performing different tasks on virtual keyboard interface, observing their behaviour on accomplishing their text composition task and then to develop a model based on the gathered data. The model would become suitable towards developing an efficient virtual keyboard providing minimum visual search time. Also, the developed model can be applied for other cognitive task around UIs and other text composition interface to further judge the usefulness of the model.

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