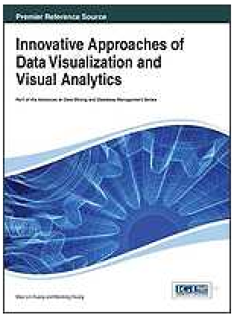

Innovative Approaches of Data Visualization and Visual Analytics

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Chapter 3: Understanding Spatial and Non-spatial Cues in Representing Categorical Information

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ABSTRACT

The continuously increasing amount of digital information available to computer users has led to the wide use of notification systems. Although these systems could support the management of information, they could also be an interruption to primary work. To minimize this interruption, a number of approaches, which notify the different categorical information, have been introduced. In this work, we focused on understanding the effectiveness of different types of visual cues to effectively represent categorical notification. Five basic visual parameters of motion, colour, shape, motion and spatial were chosen to represent sets of two categories, four categories, six categories and eight categories of information. The effectiveness of these visual cues in assisting users' ability to decode the categorical cues was examined through a series of experimental studies. Findings suggest the superiority of using colour, shape, and spatial cues to represent categorical information. Post experiment questionnaire reveals possible reasons for their efficiency. Spatial memory supports spatial cues while linguistic influence supports the shape/colour cues. The unsuitability of size parameter is possibly due to not being able to measure the cues against something during the encoding process. This makes it difficult to determine how each cue differs from the rest of the cues in the parameter, especially when number of categories increase. As for the motion parameter, encoding the cues took far longer response times, although time taken is consistent across number of categories. The different effects of these basic visual cues suggest the importance of careful design selection to ensure successful visualization.

INTRODUCTION

Notification systems have been widely used in recent years in order to provide the necessary awareness for users. This includes informing on the activities of other users, shared documents that have been created, new emails that have been received and many more. In other words, notification systems could be used to provide various types of information sources by a variety of user interface designs. The most common selections to represent these notifications are visual, auditory and combination of both dimensions.

The effects of visual designs on user's attention have been investigated by many (Hoffman, 2008; Khan, 2005). In these studies, design properties such as colours, luminance, shapes and so forth were investigated to understand which design is most suitable to direct user's attention towards targeted items. Others might be more interested in the effect of design towards user's ability to carry out dual activities, of both primary task and keeping aware of information from notification systems(Maglio, 2000; McCrickard, Catrambone, Chewar, & Stasko, 2003). In those studies, authors investigated the effects of several types of moving texts that delivers information. The direction of the texts as well as the frequency of the movement was among the parameters of interests.

In this study, we are interested to find the effects of different visual properties on user's ability to recognize the meanings they represent. We believe that this study would be useful in designing categorical notification systems. Categorical notification system means that there exist several categories within the system in order to provide users with more information of the new notification. For instance, in managing emails, users could categorize them into groups depending on sender. Thus, when a new email arrives, the notification system will automatically indicate which category that email is grouped into. This allows users to easily decide whether the notification should be attended to immediately or not. Thus, unwanted interruptions could be avoided.

BACKGROUND

1 Notification Systems and Design Consideration

The fast and dynamic exchange of information in today's workplace means that users' management of that information is highly critical. Thus, notification systems have been widely used to provide appropriate support in that matter. Using various visualization approaches, these systems keep users aware of current happenings. Ideally, notification systems should be able to notify users the availability of new and valuable information in an efficient way and be attended to at least a certain degree(McCrickard, Czerwinski, & Bartram, 2003). It is essential that it is not disruptive to primary tasks, while being salient enough to grab user attention when it is highly needed.

Various visual designs have been proposed in order to create appropriate notification systems. Systems could represent various types of data, new email, availability of colleagues, stock prices and many more. These variations also mean that design selections could be data and domain specific. For instance, a majority of notification systems that alert users on new emails use 'badge' to represent information. A numerical number in a 'badge'-like visual icon indicates how many new pieces of information have arrived and also how many have not been attended to. Other examples include the use of different types of moving texts to represent stock prices, and different colours to represent the availability of colleagues.

The designs of notification systems are not limited to visual cues that represent information. Visual and auditory cues have also been evaluated to provide awareness on risky situations in dark rooms(Kanai, 2008). An auditory based prototype system named AudioAura has been developed to provide awareness on people's physical actions within a workplace, such as location of a fellow colleague (Baer, 1998).

The design of those auditory cues manipulating different sound effects, music, voice, or a combination of those cues was investigated to explore issues such as privacy and work practice. It has been suggested that application of auditory cues could also be useful in dual-task scenarios. For instance, simultaneously carrying out item search assisted by auditory cues is easier than purely visual cues, when users are walking, as he/she needs to pay attention to the surroundings(Yu, 2010). This means that when a user carries out other tasks that require visual attention, it is an advantage to apply audio cues so that the visual modality is not burdened. Other modalities such as tactile and olfactory have also been investigated (Bodnar, 2004; Chan, 2008), although they have not been a popular choice in notification systems.

In a workplace environment that requires users to have constant interaction with displays, visual cues are most appropriate due to user attention that is already on the display. Furthermore, visual cues could support individual awareness without being interruptive to other colleagues. Investigations on different effects of visual cues such as ability to attract attention(Bartram, 2003; Hoffman, 2008; Khan, 2005) and ability to provide information without being interruptive (Maglio, 2000; McCrickard, Catrambone, Chewar, & Stasko, 2003) suggest the design trade-off of each visual cue. Therefore, it is important to employ suitable design based on users' aims, to ensure a successful notification system. Taxonomy of notification systems has identified four design questions that need to be known before a system could be built (Pousman, 2006). There are the information capacity, notification level, representational fidelity and ecstatic emphasis. While 'Information Capacity' involves the amount of information sources a system represents, 'Notification Level' means the degree of interruption given to users. 'Representational fidelity' describes how the data is encoded, and 'Aesthetic Emphasis' describes the relative importance of aesthetics used in the system. In another study, the costs and benefits of design selection is discussed. In order to compare design selections (McCrickard & Chewar, 2003). Authors discussed three key points that should be considered when making design selections, comprehension, reaction and interruption. 'Comprehension' is when information obtained could be stored for future use. 'Reaction' is when response is made after information has been received. 'Interruption' involves the reallocation of attention from primary task. For instance, when the goal of a notification system is to provide low interruption, high reaction and low comprehension, small sized and in-placed moving texts could be implemented.

2 Notification and Interruption

In designing notification systems, the effects of interruption should not be taken lightly. The degree of interruptions caused by notification systems should be selected based on the importance of the information sources. When importance is low and only general awareness of new information needs to be provided, calm and peripheral interfaces could be applied. On the other hand, salient type of notification that attracts user attention is needed when new information needs to be addressed instantly. However, when user goals and system design do not match, notifications could possibly be interruptive to users' primary task. Interruption is costly, especially to fast and stimulus driven main tasks (Czerwinski, 2000).

Past studies have suggested that interruption could be controlled by exploiting interruption lag(Andrews, 2009; Trafton, 2003). Interruption lag is when there exists an interval in between an alert and actually attending to that alert. This interval allows users to make better preparation on current task so that resuming to it later could be easier. Another approach to limit interruption is by varying the frequency of notification. Interestingly, it has been suggested that frequent interruptions allow users to resume back to primary task faster than infrequent interruptions (Monk, 2004). It is possible that the rapid switching of tasks force users to adopt a strategy that involves actively rehearsing their suspended goals during interruption. In another study, McFarlane has identified and compared four primary methods of coordinating user's interruption (McFarlane, 2002). According to the investigation, user interface that supports the negotiation of interruption is the best solution, compared to other methods of immediate, mediated and scheduled interruptions. It has been suggested that a user's characteristic, whether a polychromic user of a monochromic user, influences how he or she perceives the interruption level and the preference to rapidly attend to them or not (Huang, 2007). However, the differences in user characteristics do not influence user's ability to divide his or her attention in a dual-task paradigm rapidly.

One of the ways to control interruption level caused by overflowing notifications is to categorize the information represented by those notifications. Categorization could be made based on who the sender is, the importance of the notification, the contents and many more. Therefore, users not only are aware that something new has happened, but also given some extra information about the situation. This allows users to prioritize his or her current task, or whether it is worth attending to the newly arrived information. Categorical notifications could be represented by cues of various interface designs, and these representations are usually learned in the beginning of using those systems. It is essential to understand the effect of those representations towards human behaviours, and how a careful design selection has to be made in order to suit them with user goals.

3 Categorical Notifications

As discussed earlier, categorizing information in notification systems could provide extra information that guides user's decision-making process. Based on this extra information, users are able to make better judgment whether to attend to notification immediately or later. For instance, pieces of information could be categorized into 'family' and 'colleagues' in emails to narrow down the sender. Then, if a user is notified that a new email has arrived, attendance to it could be made based on its relative importance with the current task.

A notification system called Scope (Dantzich, 2002), visualizes multiple information based on various design properties. Multiple information sources such as emails, appointments and alerts are displayed on a circular radar-like design, where the more urgent a notification is, the more centrally it is placed. Different shapes, colours, brightness, and animated cues were also employed to indicate other specific meanings (Figure 1). This allows users to observe items in a low-effort way. However, as there are many properties visualized in the system, the identification of the meanings of those items may be difficult. For instance, the original design of scope shows issues in the colour selection of cues that did not contrast well with the background. Also, too many information presented (thus too many visual cues) questions the value of information and their necessity. If a system becomes too complex to be used, it is possible that it might infer more interruption to users, as they need longer time to encode information.

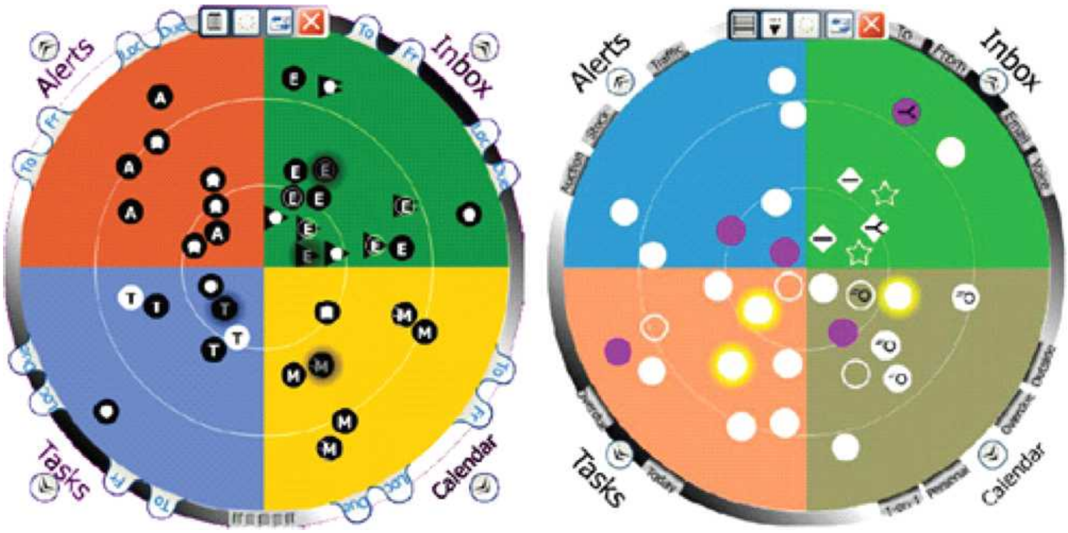

Figure 1: Scope's original design (left) and refined design (right)

The use of notification system that unifies multiple information using basic visual cues could be described with commercial system like Dockstar (Ecamm, 2013). Dockstar allows users to control the visual representation used based on their preference. Each cue is located within a different area of an icon, and they could be modified by users' preferred colour, shape and size (Figure 2). Dockstar supports the monitoring of different email accounts simultaneously, as each account is represented by a notification cue.

Figure 2: The examples of design selection in Dockstar

ENCODING VISUAL PARAMETERS

The categorization of information is commonly represented by texts. However, there have been suggestions that graphical user interfaces could support faster user response and higher user preference compared to text-based interfaces in a variety of tasks (Davis, 1992; Rauterberg, 1992; Staggers, 2000). Furthermore, if textual information could be substituted by graphical elements, less screen space is needed. This is especially useful for mobile devices as display size is more limited compared to desktop computers.

Therefore, the investigations carried out in this study aim to attain other visual parameters that could support the same goal. While the fundamental of visualization with regards to visual parameters and data types have been studied (such as Jaques Bertin's Semiology of Graphics[Bertin, 1983]), we believe that it would be valuable to investigate the relationships between basic visual parameters and human's categorization capability. To construct visual cues optimally we first break down the types of cues into spatial and non-spatial cues. Non-spatial cues consist of colour, shape, motion and size conditions that represent information. User's abilities 1) to differentiate each cue from the others within the same condition and 2) to encode the information they represent were tested. The correlations between cue and memory, as well as cue and differentiation ability are discussed as follows,

Cue and Memory

We first lay out the importance of memory in the management of information sources associated with visual cues. Past works have suggested a strong relation between memory and spatial information. The method of loci, for instance, is a well-known mnemonic associating spatial relationships to establish, order and recollect memorial content (Yates, 1966). The benefits of spatial memory has been explored in many contexts such as keeping track of rapidly changing information (Hess, 1999) and guiding interrupted users in task resumptions (Ratwani, 2008).

It has also been suggested that spatial location is memorized automatically (Andrade, 1993). That means that difficulty of tasks and the amount of attention given on the memory task have no effect upon spatial memory performance. The memory for colour and size however, are by no means automatic. Memory could be improved by instructions to attend to those colour and size (of text) conditions, however the consequences are that the memory performance decline for the semantic aspects of studied texts (Light, 1974). These differences contribute to the different affect or influence they bring towards other memorization tasks. For instance, as location is not modulated by learning instructions to be memorized, it does not benefit from effortful processing. Effective meaning of texts leads to better memory for spatial information regardless of whether the spatial information is learnt on purpose or incidentally (D'Argembeau & Van der Linden, 2004). In contrast, the effect of those texts only influence memory for colour when the colours are learnt incidentally together with the texts (D'Argembeau & Van der Linden, 2004).

Cue and Differentiation Ability

Differentiating cues or codes is one of the general guideline in the use of coding systems (McCormick, 1982). User performance in cue recognition is superior when the cues employed are easily differentiated (e.g. [Arend, 1987]). It is difficult to do relative comparison for non-spatial cues because users need to compare them in their memory. The ability to recognize the spatial cues however, allow a user to have attribute space on the screen and not just in one's head. Differentiating task may be most difficult when different sizes of cues are involved. As there is a limit to the suitable sizes of cues to be employed (in interface design), there would be very small difference between each one of them as more categories are represented. Different sized cues may be hard to be differentiated, especially when there is nothing to measure them against. Thus, recognizing the different representations of different sized cues could be very difficult.

EXPERIMENTS

Based on these past studies, we carried out an experiment to compare the effectiveness of visual cues to represent pieces of information in a categorical notification system. We believe that each visual parameter would influence user behaviours differently. Therefore, it is worth understanding the correlation between the characteristics of visual cue and user behaviours, so that appropriate design selections could be made.

Five basic visual cues of spatial, colour, shape, size and motion cues are tested. Investigations focus on two aspects, 1) Users’ ability to identify separate categories and 2) Users’ ability to differentiate visual cues. The impact of individual cues on these capabilities was tested through measuring the user's task performance. We refrained from employing such experiment where the user receives various notifications as they go about other activities, because the response time would then be contaminated with the time taken for users to first notice the cues. We were interested in the situation that users need to extract some pieces of information from visual cues. Since user's goal is to identify categories and differentiate visual cues, we hypothesize that,

H1-1) Spatial cues allow user to more easily identify categories and differentiate cues

H1-2) The use of colour and shape in visual cue yields better identification/differentiation performance than the use of size and motion

Subjects

The study is a within-subjects experiment and we recruited 15 people as subjects. There were 8 females and 7 males, all aged between 21 to 37 years old participating in the experiment. They were all university students in the Information Technology department. None of the participants reported themselves as colour-blind.

Interface

Subjects were required to learn and to make associations between categorical information and visual attributes of location, colour, shape, size and motion. All cues are coloured red, except for the different colour variations in testing the colour parameter. Other than the cues in the size condition, all cues are sized is 32x32 pixel, which is an accepted icon size typically integrated in websites or toolbars. Each cue represents a number, which vary in different sets and materials. There are 4 sets of each visual parameter in every material, comprises the sets of 2-categories, 4-categories, 6-categories and 8-categories. We employed 3 different materials with different cue sequence and cue choices among the subjects to avoid any potential bias. The following describes the interfaces involved in Task 1, which comprise of 5 different visual parameters, and Task 2, which serves as a distraction.

1.) Spatial

Four arrangements of 2x1, 2x2, 2x3 and 2x4 grid designs were tested to represent the effect of spatial cues. Figure 3 shows the arrangement of cues for the 2-categories, 4-categories, 6-categories and 8-categories sets. In the experiment, one of the cues will be outlined in black indicating the targeted cue.

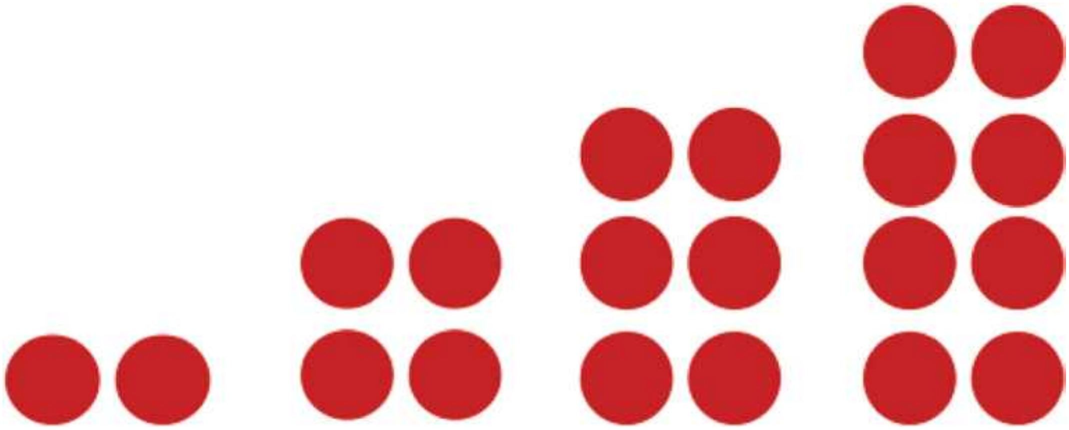

Figure 3: (from left to right) Grid arrangement for 2-categories, 4-categories, 6-categories and 8-categories of spatial cues

2.) Colour

We chose 8 basic colours, which are dark blue, orange, light green, red, yellow, purple, dark green and light blue to test the colour parameter (Figure 4). While in the sets of 8-categories all these cues were investigated to represent different categories. In other sets only a few of these cues were tested. The selection of colours used in those sets of 2-categories, 4-categories and 6-categories were randomized.

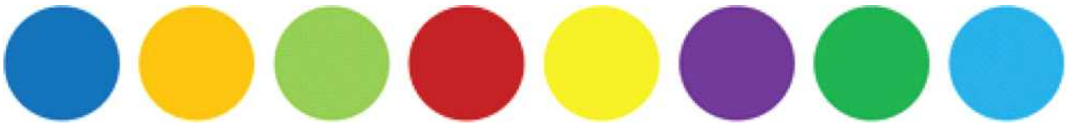

Figure 4: Basic colours used to represent information

3.) Shape

We employed 8 common shapes, diamond, triangle, square, hexagon, circle, heart, teardrop and cross, to represent the shape parameter as shown in Figure 5. Similar to the colour parameter, only the 8-categories sets will test all of these cues. The selection of colours used in those sets of 2-categories, 4-categories and 6-categories were randomized.

Figure 5: Shape cues used to represent information

4.) Size

The smallest size we employed was 16x16 pixel and the biggest size was 32x32 pixel. As the cue representations are aimed to be used in software interfaces, these sizes are the common icon/cue size employed by software designers. The size for the smallest and biggest cues are fixed, while the others are sized in between those two, according to the number of cue categories presented, as shown in Figure 6.

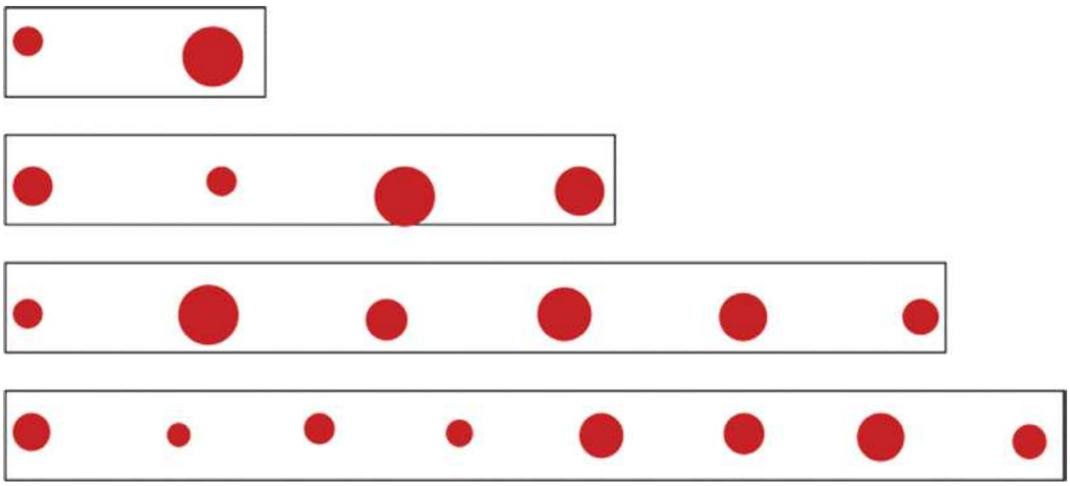

Figure 6: Different sizes used to represent different categories, top-bottom row: 2-categories, 4-categories, 6-categories and 8-

categories

5.) Motion

We employed 4 motion types and 2 motion frequencies to make up 8 cues to test the motion parameter. Blink, flicker (fade), grow and shrink type of motions moved with a fast and slow frequency, moving every 0.5 seconds and 2 seconds respectively. The grow motions increase size to 150% and the shrink motions decrease size to 50%. The cues are illustrated in Figure 7. While all of these motion cues are tested in the 8-categories sets, the cues tested in the 2-categories, 4-categories and 6-categories sets were randomly selected.

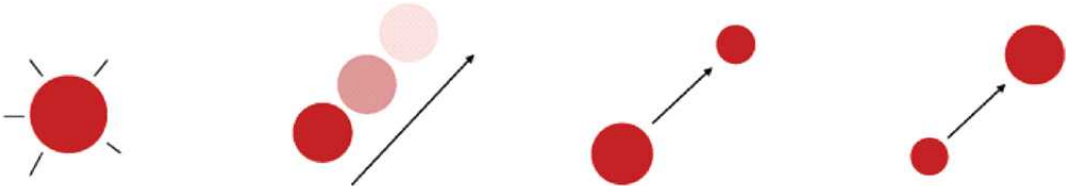

Figure 7: Different motion types used to represent information, from left: blink, flicker, shrink, and grow

Distraction Task

For the distraction task we chose a simple game, which requires participants to spot the differences, occurred in two similar pictures (Figure 8). The slides contained this task were timed for 40 seconds and participants needed to find as many differences as they could in this duration. This is to make sure information in the learning phase is stored in the long-term memory, not just temporarily as the short-term memory. Human's short-term memory fades away very quickly, and after 7 seconds, half of the information has been forgotten(Card, 1983).

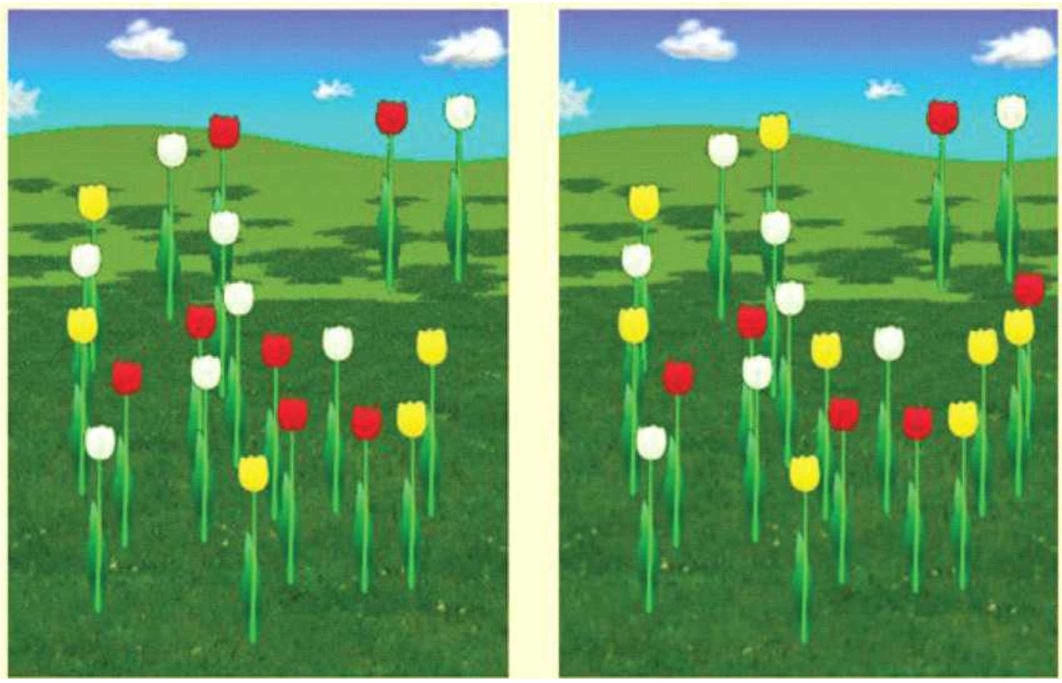

Figure 8: Example of distraction task(Spot The Difference, 2013)

Procedure

Before starting the experiment, participants were given a brief introduction to the study and the task they had to perform. Experimenter guided them through 2 sets of practice to familiarize the participants on the procedure of the experiment. The duration of the experiment varies on individual performance but took approximately 45 minutes to be carried out including survey.

In the beginning of each set, participants learnt the characteristics of the cues and the information (number) they represent. There were two, four, six, and eight items tested for each parameter. For instance, as shown in Figure 9, subjects learnt colour cues for 4 items. Participants had no time limit in the learning phase but could not review the cues again once they had ended it. Following the learning phase, participants performed a distraction task. This phase consists of a fixed 40 seconds task of comparing two similar pictures and spotting their differences. The purpose of employing the distraction task before the cue categorization task is to ensure information memorized is not just stored temporarily. After the distraction task ends, participants were shown using the mouse clicking the cue they had learnt, one by one. Each cue is presented at the centre of the interface (screen) and accompanied by two questions, one asking which number they represent, and the second question asks if the cue is identical with the one in previous slide (Figure 10). Participants need to click on the button indicating the correct answer. Bear in mind that motor control (moving cursor to target) was involved in target selection. The cue sequences were generated randomly. After the end of each set, participants went through the learning phase again. The same procedure is repeated for different visual parameters and different amount of cue items. No same visual parameter was tested sequentially. There were 4 cues tested in the sets of 2 items, 6 cues tested in the sets of 4 items, 8 cues tested in the sets of 6 items and 10 cues tested in the sets of 8 items. The same cue may appear more than once in each set.

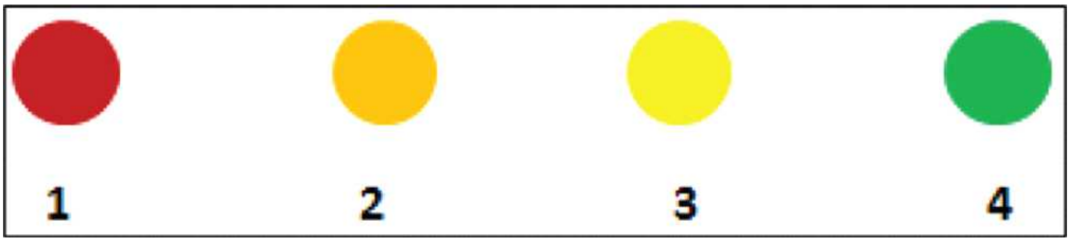

Figure 9: Four items of different colours representing different categories

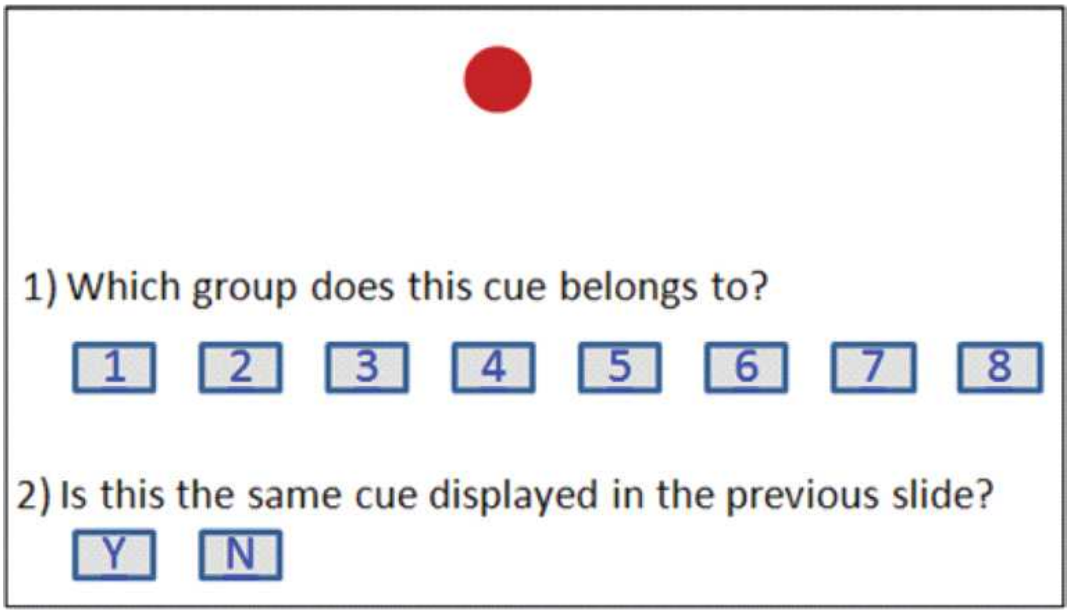

Figure 10: Cue being presented one by one, accompanied by two questions

RESULT

The dependent measures in this experiment are users' response time, accuracy, learning time and their differentiation ability. Response time (Table 1) is measured from the time the cue was presented to the time user click on a button, indicating an answer had been chosen. The data is visualized in Figure 11. Accuracy of data is measured from the amount of correct answers chosen (Table 2), and the data is visualized in Figure 12. The time participants took to learn the cues is defined from the moment cues were visible to participants until they clicked on a button to change the slide, and the data recorded as displayed in Table 3. Lastly, to prove the cues we employed were able to be distinguished from one another, participants were asked in every slide if the cues they see differ from the previous ones. We also recorded the accuracy of this answer (Table 4).

Table 1: Response times of visual parameters and number of categories

	Location	Colour	Shape	Size	Motion
2	M=2317 SD=1090	M=2195 SD=1306	M=1713 SD=896	M=2431 SD=1130	M=2950 SD=1395
4	M=2065 SD=538	M=2083 SD=450	M=2341 SD=679	M=3603 SD=1105	M=4066 SD=2000
6	M=2862 SD=726	M=2543 SD=559	M=2954 SD=828	M=4826 SD=2023	M=5113 SD=2146
8	M=3076 SD=902	M=4014 SD=1474	M=2721 SD=1170	M=3739 SD=1727	M=9792 SD=16777 Corrected: M=5743 SD=2106
Ave	M=2580 SD=915	M=2709 SD=1284	M=2433 SD=1006	M=3650 SD=1733	M=4468 SD=2169

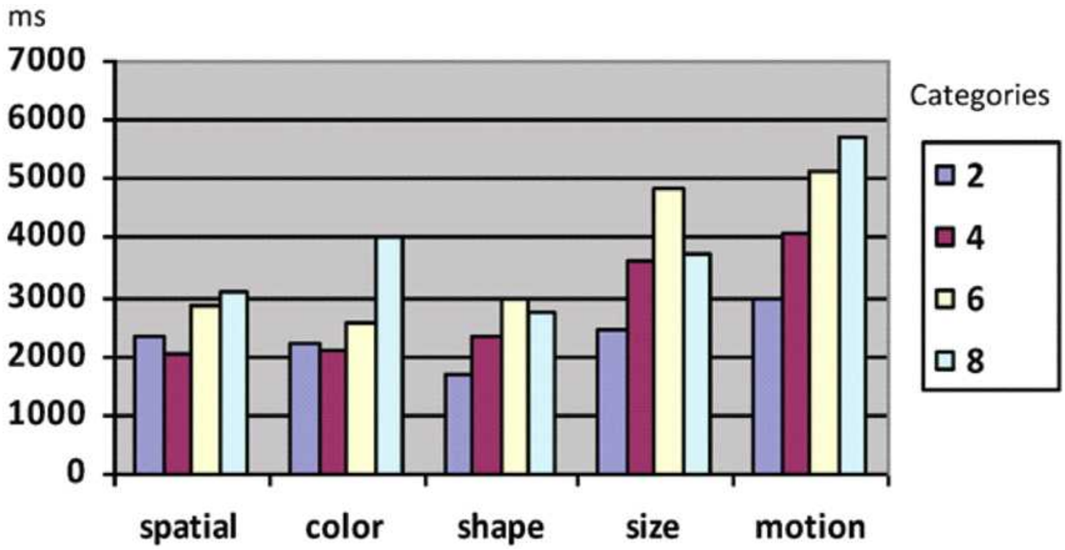

Figure 11: Response times of visual parameters and number of categories (ms)

Table 2: Accuracy of visual parameters and number of categories

	Spatial	Colour	Shape	Size	Motion
2	M=0.93 SD=0.26	M=0.93 SD=0.26	M=1.0 SD=0	M=0.93 SD=0.26	M=0.93 SD=0.26
4	M=0.99 SD=0.04	M=0.91 SD=0.18	M=0.97 SD=0.09	M=0.63 SD=0.32	M=0.84 SD=0.24
6	M=0.85 SD=0.28	M=0.93 SD=0.14	M=0.84 SD=0.26	M=0.52 SD=0.25	M=0.76 SD=0.35
8	M=0.91 SD=0.16	M=0.77 SD=0.31	M=0.89 SD=0.22	M=0.31 SD=0.23	M=0.59 SD=0.30
Ave	M=0.92 SD=0.21	M=0.89 SD=0.23	M=0.92 SD=0.18	M=0.6 SD=0.34	M=0.78 SD=0.31

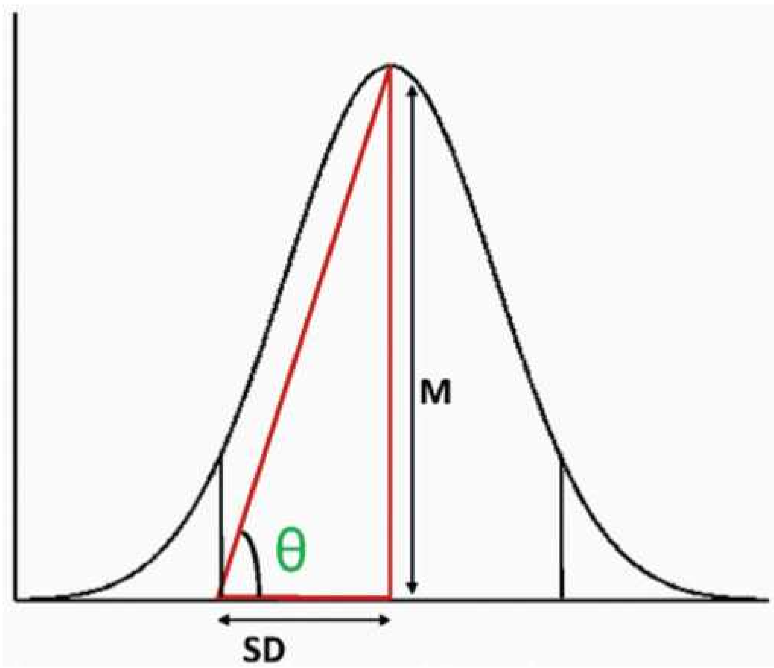

Figure 12: Relationship of θ and M/SD in each data distribution

Table 3: User's learning time of visual parameters and number of items

	Spatial	Colour	Shape	Size	Motion
2	M=3204	M=4199	M=3837	M=5647	M=8548

	SD=1634	SD=2144	SD=1872	SD=3957	SD=2323
4	M=4919 SD=3411	M=12583 SD=7848	M=13634 SD=5678	M=18090 SD=12295	M=30515 SD=9819
6	M=10364 SD=6586	M=20596 SD=12113	M=33021 SD=13656	M=32699 SD=21061	M=62676 SD=27623
8	M=24524 SD=13046	M=45857 SD=35728	M=45817 SD=24453	M=37248 SD=24709	M=85389 SD=53609
Ave	M=10753 SD=11201	M=20809 SD=245001	M=24077 SD=21610	M=23421 SD=21160	M=46782 SD=42063

Table 4: User's differentiation ability across visual parameters and number of categories

	Spatial	Colour	Shape	Size	Motion
2	M=0.92 SD=0.12	M=0.97 SD=0.09	M=0.97 SD=0.09	M=1.0 SD=0	M=0.95 SD=0.1
4	M=0.93 SD=0.1	M=0.99 SD=0.04	M=1.0 SD=0.0	M=0.96 SD=0.08	M=0.86 SD=0.22
6	M=0.98 SD=0.06	M=0.99 SD=0.03	M=0.98 SD=0.04	M=0.94 SD=0.06	M=0.95 SD=0.08
8	M=0.99 SD=0.04	M=0.99 SD=0.04	M=0.99 SD=0.03	M=0.97 SD=0.06	M=0.97 SD=0.08
Ave	M=0.96 SD=0.09	M=0.98 SD=0.05	M=0.99 SD=0.05	M=0.97 SD=0.06	M=0.93 SD=0.14

The standard deviation of response time in motion 8-categories set is high (see Table 1), and based on z-score we found one outlier (z-score 3.59) which is then corrected. This is visualized in Figure 9. We then ran two-way ANalyses Of VAriance (ANOVA) to compare participants' response times in different number of items and visual parameters. There was a significant effect of visual parameters on user response time, $F(2.23, 31.21)=19.92$, $p<0.001$. Pairwise comparisons revealed that response time is significantly different between size and location ($p<0.05$), size and colour ($p<0.01$), size and shape ($p<0.01$), motion and location ($p<0.001$), motion and colour ($p<0.01$) as well as motion and shape ($p<0.001$). The mean and standard deviation of those visual parameters could be referred in Table 1. The was also a significant effect of number of categories towards response time, $F(3, 42)=24.83$, $p<0.001$. Pairwise comparisons revealed significant difference between 2-categories and 6-categories ($p<0.001$), 2-categories and 8-categories ($p<0.001$), 4-categories and 6-categories ($p<0.05$) as well as 4-categories and 8-categories ($p<0.001$). The mean and standard deviation of those visual parameters could be referred in Table 1. The was also a significant interaction between visual parameters and number of categories, $F(12, 168)=3.652$, $p<0.001$. This indicates that the effect of visual parameters on user's response time depends on the number of categories employed.

The superiority of visual parameters could be observed through user's accuracy, response time and learning time. Another factor that could determine its superiority is stability across users. Consider two different visual parameters, A and B that has the same user response time. However, the standard deviation in condition A is much higher than condition B, indicating data points that are spread out over a large range of values. This means that the stability of condition A is lower than B, and that different user might response to it differently, some good and some bad. In order to understand deeper the visual parameters we are investigating, we also investigate their stability across users. The methodology is described as follows,

As seen in Figure 12, a triangle could be created in each data distribution. The horizontal axis indicates the standard deviation of data while the vertical axis indicates the mean of data. Therefore, $\tan \theta = \text{mean/sd}$. The bigger value of θ indicates a smaller ratio between mean and standard deviation, which suggests that data points are very close to mean. This shows the stability of data across different users. The area of triangle could also be calculated, reflecting the correlation between mean and standard deviation. When mean and standard deviation are both small in value, a small area of triangle could be obtained. Similarly, when mean and standard deviation are of big values, a large area of triangle will be obtained. Based on these two values (area of triangle and θ) we visualize the response times of visual parameters investigated in Figure 13. A data value that falls on the right and bottom area of the graph (high θ value, small triangle area) indicates overall superiority, where both SD and mean are small. While the horizontal axis indicates the distribution of data, the vertical axis indicates mean value. Different visual parameters are indicated by different colour of data points, while the bigger points indicate the average of each parameter. The lines connecting those points are visualized to assist in tracking progression from lower number of categories to the higher.

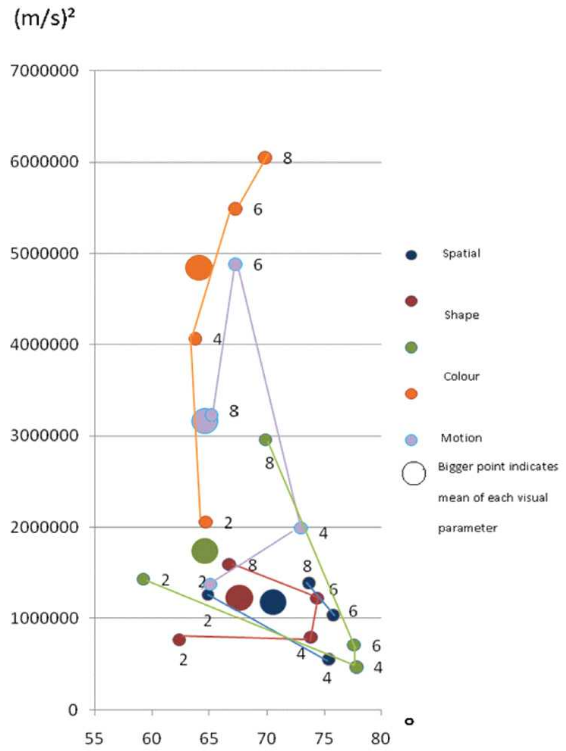

Figure 13: Comparing the stability of visual parameters across users (response time)

To interpret the Figure 13, the 4-categories and 6-categories sets of location, colour and shape cues show overall superior performance where stability across different users are high and low mean values. In contrast, cues in the motion parameter show the higher mean values with low stability across users, regardless of number of cues.

Findings of user accuracy across different visual parameters and number of categories (Table 2) suggest different user performance especially when involving larger amount of items categories. Figure 14 visualizes this data. We then apply statistical analysis for a deeper understanding of their correlations. Logistic regression applied on accuracy show a statistically significant effect of visual variables ($p<0.000$) and effect of number of items ($p<0.000$) towards accuracy. Analyses also indicate significant difference between location (reference) and colour ($p<0.05$), size ($p<0.000$), motion ($p<0.000$). We also found a negative value of coefficient B (-0.328) when analysing the effects of number of categories on accuracy, indicating that accuracy is greater with lesser number of categories.

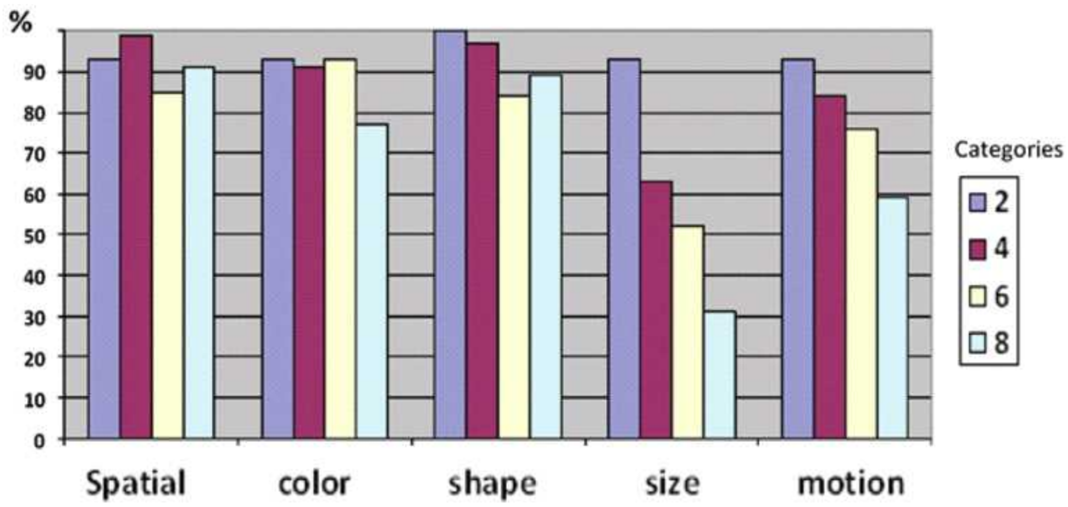

Figure 14: Accuracy of visual parameters and number of categories

Similar to finding stability of visual parameter based on user response time, we plotted the same graph based on user accuracy (Figure 15). The number of categories is inserted on each point accordingly. Bigger points indicate the mean of data. Based on the mean data points, superior results, which is the stability of visual parameter across users as well as higher accuracy in user performance, are shown by shape, location and colour, compared to size and motion parameters.

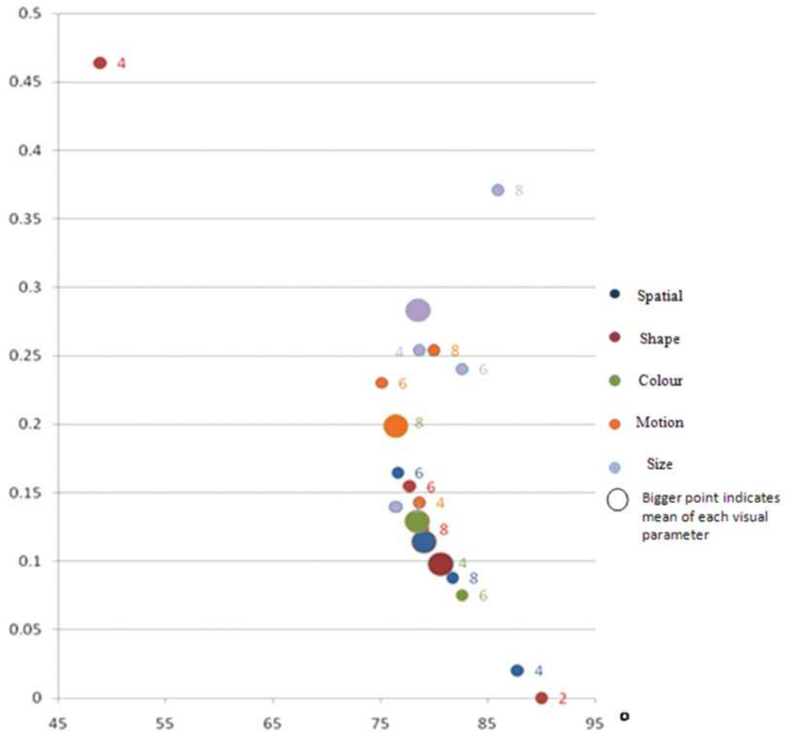

Figure 15: Comparing the stability of visual parameters across users (Accuracy)

We also ran two-way ANalyses Of VAriance (ANOVA) to compare the learning time participants took, comparing the number of categories and visual parameters. Findings indicate significant effect of visual parameters on user response time, $F(4, 56)=30.76$, $p<0.001$. Pairwise comparisons revealed significant difference between location and other visual parameters, with colour ($p<0.05$), shape ($p<0.001$), size ($p<0.01$) and motion ($p<0.001$). Participants took significantly longer time to learn the motion cues compared to other cues, with colour ($p<0.001$), shape ($p<0.001$) and size ($p<0.01$). The data could be referred in Table 3. There was also a significant effect of number of categories towards learning time, $F(1.18, 16.55)=47.31$, $p<0.001$. Participants took significantly shorter time to learn the cues in 2-categories compared to 4-categories, 6-categories and 8-categories ($p<0.001$). They also took significantly shorter time to learn 4-items cues compared to 6-categories and 8-categories ($p<0.001$). 6-categories cues were significantly different to learn compared to 8-categories cues ($p<0.01$). Data is visualized in Figure 16.

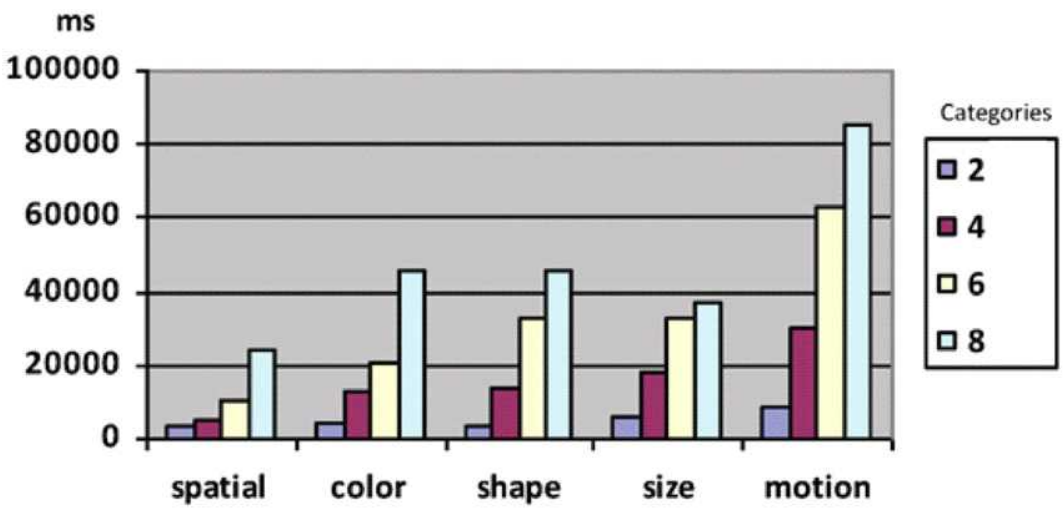

Figure 16: Learning time of visual parameters and number of categories

There was also a significant interaction between visual parameters and number of categories, $F(3.41, 47.69)=5.77$, $p<0.001$. This indicates that the effect of visual parameters on user's learning time depends on the number of items used. We ran contrasts analyses and compared all item size to their baseline (2-categories) and all visual parameters to their baseline (location). These revealed significant interactions when comparing location and colour parameters for 2-categories compared to 4-categories ($F(1, 14)=19.27$, $p<0.001$), 2-categories to 6-categores ($F(1, 14)=17.17$, $p<0.001$), and 2-categories to 8-categories, $F(1, 14)= 4.64$, $p<0.05$. There is also significant interaction when comparing location and shape parameters for 2-categories compared to 4-categories ($F(1, 14)=32.93$, $p<0.001$), 2-categories compared to 6-categories, $F(1,14)= 48.69$, $p<0.001$ and 2-categories to 8-categories, $F(1,14)= 14.87$, $p<0.01$). When comparing location and size parameters, again significant interaction is found for 2-categories compared to 4-categories, $F(1, 14)= 17.2$, $p<0.01$) and between 2-

categories and 6-categories, F(1,14)=13.68, p<0.01). Lastly, significant interactions were revealed when comparing location and motion for 2-categories compared with 4-categories (F(1,14)=52. 83, p<0.001), 2-categories compared to 4-categories (F (1,14)=41.37, p<0.001) and 2-categories compared to 8-categories F(1,14)=17.9, p<0.001.

We also show the stability of parameter when users are learning cues, which is visualized in Figure 17. Based on this graph, on average, the stability of motion, shape and size cues are higher than spatial and colour cues (Mean data for each visual parameter is shown with a bigger icon). However, users took the least time to learn cues in the location condition compared to other parameters, and longest time in the motion parameter

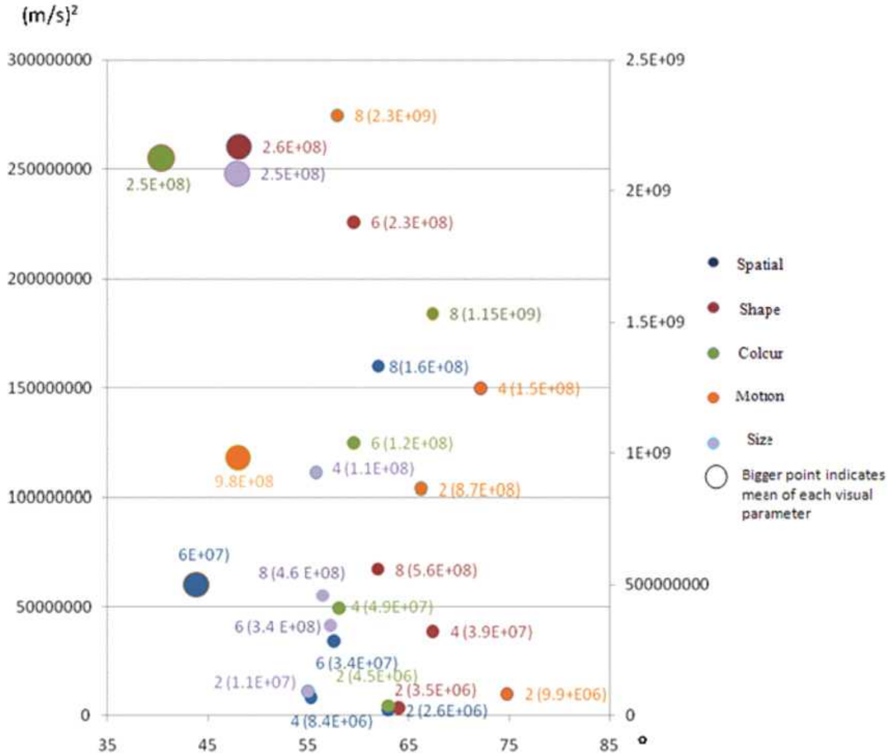

Figure 17: Comparing the stability of visual parameters across users (learning time)

In order to make sure that each cue we employed could be differentiated with the rest, participants were asked whether each cue they were viewing (during the experiment) were the same with the previously seen cue. The data collected is shown in Table 4. We ran logistic regression as the data was binary, and findings revealed no significant effects of visual variables or number of categories. Subjects generally had no trouble to differentiate the cues against one other cue at each time. We visualize the interaction between visual parameters and number of categories in Figure 18.

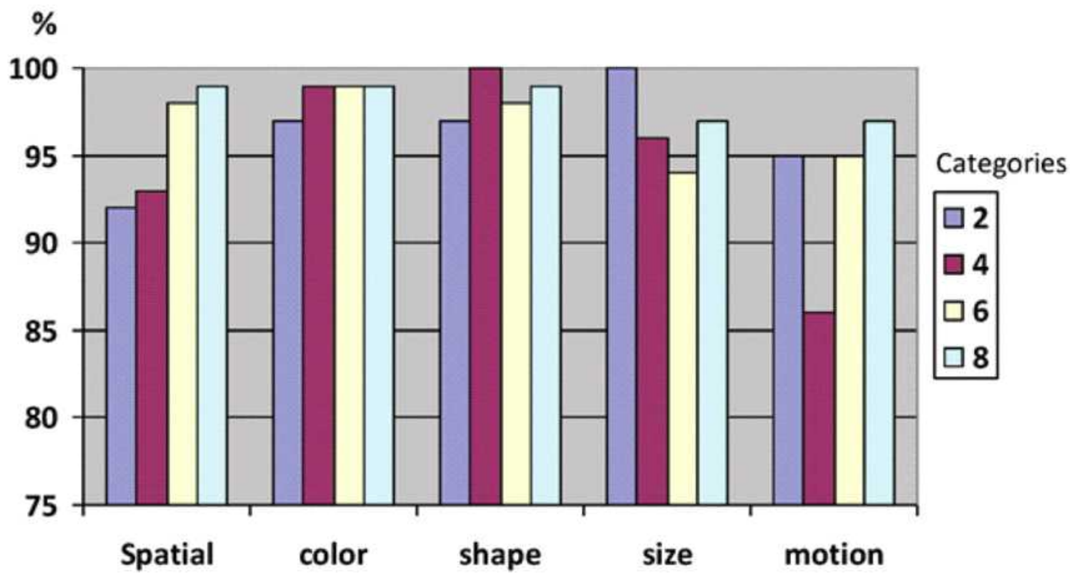

Figure 18: Differentiation ability across different parameters and number of categories

Participants were also required to evaluate the visual cues based on 3 questions. The evaluation was tested on the 5-point Likert scale, where rating '1' indicates 'strongly disagree' and '5' indicates 'strongly agree'. They were also required to provide appropriate comments for their ratings. The questions and results based on Kruskal-Wallis Mann-Whitney tests are as follows:

- **Q1:** It was easy to learn/memorize the group (number) each cue represents.
  - Mean rank for location, colour, shape, size and motion cues are 50.77, 52.17, 48.60, 12.80 and 25.67 respectively ($p<0.001$). Post hoc analyses reveal significant differences between location A (reference) and size ($p<0.001$) as well as with motion ($p<0.001$) but not with other perimeters.
- **Q2:** It was easy to recall the group (number) each cue represents even after distraction.
  - Mean rank for location, colour, shape, size and motion cues are 51.67, 50.33, 45.93, 16.70 and 25.37 respectively ($p<0.001$). Post hoc analyses reveal significant differences between location A (reference) and size ($p<0.001$) as well as with motion ($p<0.001$) but not with other perimeters.
- **Q3:** It was easy to differentiate each cue to the rest.
  - Mean rank for location, colour, shape, size and motion cues are 48.77, 48.60, 50.17, 15.33 and 27.13 respectively ($p<0.001$). Post hoc analyses reveal significant differences between location A (reference) and size ($p<0.001$) as well as with motion ($p<0.001$) but not with other perimeters.

Based on the questionnaire results we found that most participants relied on mnemonics to aid the learning phase. A majority stated it was easier to learn and recall cues in the location condition, but faced difficulties to differentiate sizes as they were not able to compare the cues with something. A few participants found that motions get drastically harder to recognize when there are more cues present, as they get more complicated. A few participants also revealed that reproducing recall was more difficult when there were two tones of the same colour in the set of cues. In order to learn the non-spatial cues, some of the participants revealed that linguistic associations were made. However, they were only successful in the colour and shape cues. These names were then linked to make a 'story', and producing recall was much easier. However, as size and motion cues could not be named, learning and retrieving these cues becomes difficult.

DISCUSSION

Due to the fact that spatial cues could automatically support memory (Andrade, 1993) and better differentiation of cues as they are physically visible on screen, we have predicted superior user performance of spatial cues compared to other non-spatial attributes. However, findings suggest that colour and shape cues are equally as efficient as spatial cues, while motion and size cues show constant weakness.

While accuracy and response times are similar for spatial, colour, and shape cues, learning time for spatial cues was significantly shorter. Findings from questionnaires provided some understanding of these differences. It seems that learning spatial and non-spatial cues were supported by different techniques and processes. While spatial cues are supported by spatial memory, colour, and shape cues were learnt based on linguistic associations of cues and the meaning they represent. Thus, naming the cues was a major element that supports the learning process. Linguistic influence on human behaviours is not something new, as was explored by psychologists in the past. Whorf has reasoned that people could only think about the things their language could describe(1940). His ideas were developed by comparing several language structures and the behaviours and world views of the people who speak those languages. Based on Whorf's view, studies have shown that linguistic associations do support colour memory in both short-term and long-term tasks (1940). The effect of giving names to discriminate stimuli was also stressed in Miller's suggestions as to make patterns less similar (1948).

We had also observed poor user performance in the size and motion parameters. As the variation of cue size employed is limited, as to meet the standard size of cues typically designed, the differentiation of cues becomes very difficult. Although the differentiation task we employed showed that subjects were able to discriminate each cue to another cue at a time, it is possible that difficulties actually lies in judging how much each cue differs to the rest of the cues in the condition. This becomes more challenging as the difference between cues become smaller, or in other words, larger number of cues to be aware of. To overcome this problem, certain visual cues could be added to support measurement so that size differences could be properly judged. Motion cues not only require the most time to learn, but also to be identified. This could be explained that the presentation of each motion cue to complete one cycle requires longer time to be observed compared to static cues. Furthermore, in this study we employed motion cues with two characteristics, type of movement and frequency, which may require more mental effort. As response time towards motion cues are significantly longer then the static cues, it is unsuitable to be applied in this context as it would be too long or too much that is required to be distracted from users' main task in real-life scenarios.

Interaction between visual cues and number of categories were found to influence user performance in their accuracy, response times and learning time. This indicates that user's response differently towards number of items depending on the visual cue used. When the stability of visual parameters across users was evaluated, shorter response time was shown in the 4-categories and 6-categories sets. It is possible that users took longer to response in the 2-categories and 8-categories due to confusion and information overload. However, compared to colour/shape cues, this effect is not very obvious in the spatial condition, suggesting a superior effect of spatial cues. As suggested in past studies, there is a strong correlation between location and human memory, called spatial memory (Andrade, 1993; D'Argembeau & Van der Linden, 2004; Hess, 1999; Ratwani, 2008; Yates, 1966). Thus, this might be support retrieval of information. The stability of visual cues was also investigated for user's accuracy in the experiment as well as their learning time. The mean accuracy shows that location, shape and colour cues not only provide higher accuracy but also more stable across different users, compared to size and motion cues. Furthermore, the most stable cues involve smaller amount of cue categories represented by the shape and location cues, while the least stable ones involve bigger amount of cue categories represented by size and motion cues. Due to these differences, the application of size and motion cues should be avoided in the representation of categorical notification as user ability to accurately response to those cues varies. The stability of cues was also demonstrated in user's learning time. Findings suggest that the learning time is faster for some users but slower for some. Meanwhile, the learning time for motion, shape and size cues seem to be more stable across users. In other words, all users took approximately similar duration to learn the motion, shape and size cues.

Findings from our experiments demonstrate that categorical information could be supported by non-textual notifications, with little learning time. Designers should employ spatial cues to represent categorical information, and while colour/shape cues occupy less space, the selection of those cues is crucial. As there may be possibilities that users code and encode colour/shape cues by linguistic associations, designers need to consider user's ability to discriminate the cues and that any similarity could contribute to confusion and failure of the design interface. Furthermore, it is important that the number of cues or categories displayed in a system is controlled. In order to prevent cognitive overload.

CONCLUSION

The relationship between visual cues and users' ability to recognize categories in a notification system was investigated. Findings suggest overall superiority of spatial, colour, and shape cues compared to motion and size cues. However, the shorter learning time and less effect of number of categories towards the spatial cues suggest that they are memorized and retrieved differently from colour and shape cues. Overall findings suggest careful design considerations involving 1) types of visual cues, and 2) number of categories represented by those cues. In order to develop successful categorical notification systems.

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KEY TERMS AND DEFINITIONS

Categorical Information: We define categorical information as the grouping of several pieces of information, whose category can be defined to identify which category each piece of information belong to. It does not have any information about ordering and distance among those pieces of information.

Non-spatial Cues: Non-spatial cues refer to cues that do not have a fixed attribute space and not defined by their location within the screen or each other. Instead, they are defined by other characteristics such as colour, size, shape and motion.

Notification System: Notification system is a tool used to deliver new information to keep users aware of current happenings. These information pieces could be represented by cues of various user interface dimensions including visual, auditory and haptic.

Spatial Cues: Spatial cues refer to cues that have fixed attribute space on the screen. They are defined by their location within the screen and each other.