Exploring the Effect of Color-Coding on Gestural Memory

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ABSTRACT
Over the last few years touch interactions have become one of the most widely used forms of inputs. While new and advanced gesture sets are developed for different interfaces, they are often limited in acceptability due to several reasons such as, not being "natural" to use, lack of quick ways to learn the gesture or the extra effort needed to learn them. In this paper we approach the problem of learning new touch gestures and propose to use color coding as an aid for teaching new single touch gestures. The motivation for selecting color coding is because it has been previously studied to have a significant impact on visual memory. In our work we investigate if the same holds for gestural memory. In this paper we present a controlled study with twenty four participants to explore the effect of learning and recalling eight new single touch gestures using color coding. Color coding gestures refers to mapping the gestural strokes by direction, i.e. up, down, left and right directions mapped to yellow, green, red and blue respectively. Results show that although there is a very small difference in mean values of the success rate that can be achieved using color-coding, there is no major statistical difference between learning and recalling new single touch gestures with or without color coding.

Author Keywords
Single touch gestures, color-coding, memory, learning

INTRODUCTION
With the advent of touch interfaces, several efforts have been made towards understanding and designing touch gestures [18]. Moving from one and two finger gestures, devices (e.g. Apple iPad) supporting ten or more touch points are incorporating truly multi-touch gestures (3 fingers and more) for performing various tasks such as, closing windows, hiding and revealing app bars etc. However, end user's may not easily adapt to the newly introduced gestures for reasons such as, lack of awareness, insufficient exposure to how to perform a particular gesture or simply not wanting to invest time into learning more gestures. Thus, to incorporate new and advanced touch gestures into our systems, one of the first steps to be taken should be to make the users aware of those new gestures and help lessen the learning effort.

From a design standpoint, the interactions are often developed either from the point of view of user experience (how natural and easy to grasp the gesture is) or from the point of view of the algorithms that the device can support [18]. However, the gesture vocabulary maybe large depending on the application and the definition of what is natural for a user to learn is hard to generalize. Miming real world experiences to create a gesture that feels easy to learn for novices as well as experts is hard to achieve if the learning of the gesture is solely dependent on user experience. Thus, beyond previous experiences and mimicking real world interactions, we also need ways that can teach new touch gestures in a quick and easy manner to allow user's to learn them.

Approaches have been taken to teach multi-touch gestures on horizontal touch surfaces such as the Microsoft Surface. Some of the commonly used techniques include: (a) using an elaborate feedback system wherein, upon initial touch posture registration the system provides the next possible dynamic trails that can be traced [1, 8], (b) use of additional windows showing the complete list of gestures represented by some form of gesture visualization (static or animated motion images [2, 4, 5, 7] (c) video tutorials [8] and (d) textual descriptions of the multi-touch gestures [5]. While each of these approaches have their own benefits and limitations, we propose to take a step back and look at simple mapping techniques that could improve our ability to learn gestures quickly with minimal learning time.

Color coding as a tool for visual learning has been explored previously [9, 12, 16]. It has been observed that color coding has a positive impact on visual memory and that there is a significant impact on learning when color is related to the content to be learned [10]. Knowing these benefits we present an exploration where we test how gestural memory could benefit from color coding. Some of the challenges and problems in doing this include the following: (a) how does our gesture design relate the color to the content being learned , in other words, how do we map the color to the gesture?, (b) how to reduce the cognitive load that maybe increased by the combination of two visual variables [3, 6] - color and motion, (c) how many colors should be used for mapping, and finally (d) how do we measure the accuracy of the touch gesture being performed.

In this paper we present our exploration of studying the effect of color coding on gestural memory, limited to single touch gestures. To do so, we present a between-subjects controlled experiment with twenty four participants. The goal of the experiment is to study if there is any differences between the color-coded group and the no-color coded group in terms of learning and recalling single touch gestures. The remaining of the paper explains the motivation for this research stemming from previous instances of research, our study design, results from pilot phase, discussions and finally conclude with some pointers for future work.

BACKGROUND

In this section we present a brief background to our motivation of using color as an instruction medium for teaching touch gestures.

Learning touch gestures

There are not many dedicated applications that are incorporated into touch devices to teach new and advanced touch gestures to end users. When new touch interactions are introduced in devices like tablets and touch phone, very rarely any teaching tool is provided, thus limiting people to learn the gestures by self discovery using trial and error or resulting in not using the advanced gestures due to the amount of time needed to get acquainted with them. To address this problem our experiment focused on exploring how touch device users can be made aware of the new touch gestures existing in a device. One of the basic steps to do this is to allow the users to learn the touch gestures in a short span of time and using simple approaches.

Some of the existing approaches to teaching touch gestures include the following: Kuternback et al. employed the use of pop-up cheat sheets and contextual animation to help users to become aware of all the available gestures [11]. OctoPocus [1], is a single touch gesture teaching aid that employs dynamic feedforward and feedback to help novice users to learn gestures. The paper also compared OctoPocus with traditional static help menu. ShadowGuides extended this concept, wherein they designed an in-situ teaching application to teach multi-touch and whole-hand gestures on interactive surfaces. The users were provided by visualization feedbacks that help to aid the user to complete the gesture posture [8]. In this paper the authors also presented a comparison between ShadowGuides and video tutorials. While both the techniques, OctoPocus and ShadowGuides, showed low error rates for learning and recalling gestures, the systems are visually elaborate to use in real interaction scenarios on smaller mobile devices like tablets and touch phones.

In our experiment we were interested in exploring simple mappings that could be taken advantage off from a given set of visual variables [3, 6] and to study if existing memory enhancing aids can be used to allow users to learn touch gestures quickly . Among, the many aids, we chose to test if color as a visual variable can benefit teaching touch gestures. The choice of color was because, color as a medium of instruction for visual memory improvement has been observed to be efficient. However, it has not been specifically used in the context of gestural memory.

Role of color as a learning aid

Color has been previously studied by researchers to better understand its function as a teaching medium. Some early attempts to identify the role of color as a learning aid include the research by, Otto and Askov and Pruisner. Otto and Askov identified that color as an instructional means was limited to being used only as a medium for carrying basic information and did not contain any additional cues to enhance learning [13]. In a latter study conducted in 1993 by Pruisner with junior high school students, it was observed that recall and retention (2 week delay) of a graphic presentation summary of a well known myth was better when the graphics was presented using color cues [15]. Similary, other researchers, such as Heinich et al. and Kleinman et al. have also shown that color coding serves as a useful visual learning aid when compared to learning using black and white visuals [9, 10].

Looking at the effect of color in the realm of HCI, Plouznikoff et al. conducted an experiment wherein participants where shown a 5x5 matrix with random digits between 0 to 9 and asked to memorize the numbers using a color and no color condition within 2 minutes. It was observed that average performance of participants increased from 47% to 61.5% using the color condition [14]. Motivated by the positive impact of color on learning, we explored if the same could be achieved for learning new touch gestures.

DESCRIPTION OF EXPERIMENT

The goal of our study is to investigate how a person will learn new single touch gestures. In particular, we would like to explore if color coding has any effect on learning new single touch gestures. To do so, we conducted a pilot study using a between subjects controlled experiment with twenty four participants and evaluated the performance of our participants for learning and recalling eight single touch four stroke gestures.

Null Hypothesis

There is no difference in learning and recalling single touch gestures when taught with and without color coding.

Definitions

- Learning is defined as the accuracy with which the gesture is performed.
- Recall rate is defined as the total time taken to identify the total number of correct gestures.
- Accuracy of a gesture in this experiment is binary. The reproduced gesture will be considered correct if all the four strokes of a gesture are correctly done with the correct direction.

Subjects

For the purpose of our pilot study we recruited twenty six graduate students from our university (8 female and 16 male). The pilot study presented in this paper however reports the results from only twenty four of our participants. We had to leave out the results from two of our participants because of technical problems with the camera in one of the sessions and

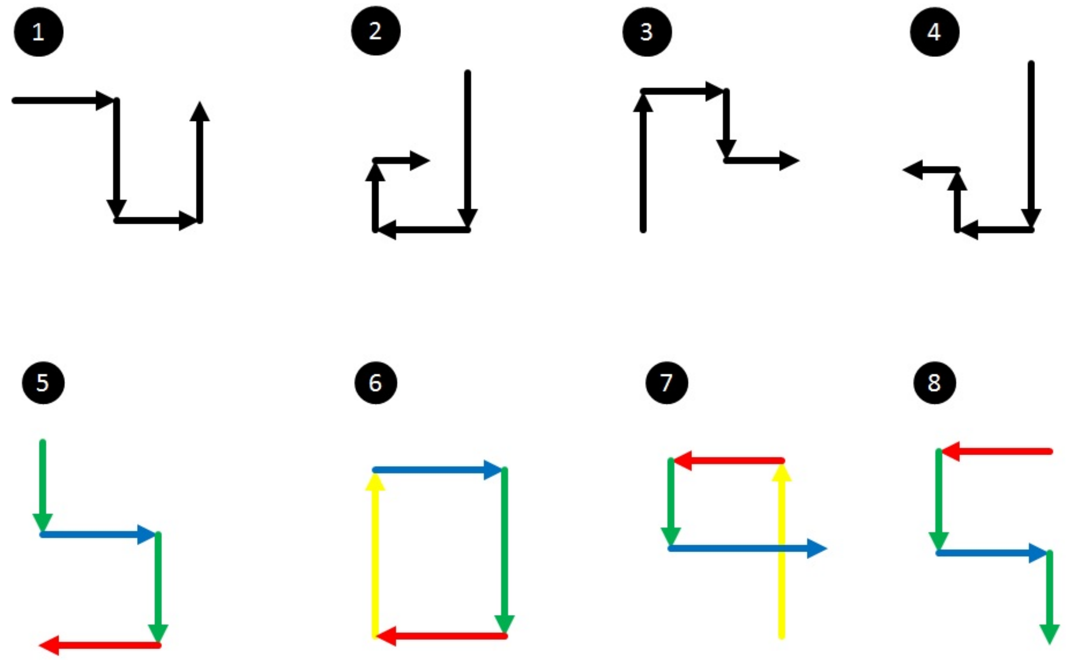

Figure 1. Gesture set used in this study.

lack of participant attention in the second session. The participant mentioned that he had not paid attention to the instructions being given and did not understand that he had to recall the gestures during the test phase. The participant also mentioned that he assumed that he would use the gestures within a task setting with some help and hence could not recall any gesture.

Due to the between participant study design the participants were divided into two groups (12 participant each) - **A: color** and **B: no color group**. The assignment of the participants to the groups was randomized [17] so as to avoid any biases. At the time of sign-up participants were requested to let the researchers know if they had any problems identifying the colors red, green, blue and yellow. This was done to ensure that we did not assign these participants to the controlled group testing color-coded gestures. Using a pre-test questionnaire we gathered that all our participants owned a touch device and their touch interaction usage was on a daily basis.

Materials

The experiment was conducted on the Microsoft Surface 2.0, multi-touch tabletop. The eight gestures used in the study are as shown in Figure 1. Gestures 1 to 4 demonstrate the color coding employed for the no-color group and gestures 5 to 8 illustrate the color coding employed for the color group. The interface for this study was a simple 10 X 20 grid as seen in Figure 2. Participants could draw the gesture on the grid as seen in the figure using a single finger. The same interface was used to administer both the learning phase and the test phase. Since all the eight gestures demonstrated on this study were a combination of horizontal and vertical strokes, the grid was used as means to help participants to draw clean straight strokes with fewer curves. The entire session was video recorded with the consent of the participants. The video recordings were latter used to analyze the accuracy of the gestures during the test phase and to gather the time taken to recall the gestures.

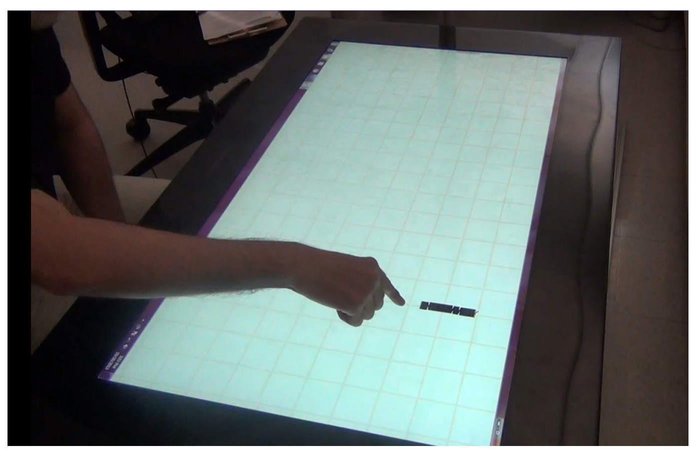

Figure 2. User interface

Method

To conduct this experiment we chose to use a between subjects controlled experiment design. The choice of between subjects was to ensure that there would be no learning effect. Prior to starting the study we divided our participants into the two conditions, A - color and B - no color. The allocation of group members was done using random assignment

[17]. However, since the color category presented the gesture as a collection of strokes colored by direction (i.e. right = blue, left = red, up = yellow and down = green, Figure 1) we checked prior to participant allocation if any of our participant had problems identifying red, green, blue or yellow.

The study sessions started with a brief verbal introduction to the goals of our study (learning and performing single touch gestures) and a short pre-questionnaire to better understand the participants experience with touch devices. Following this the study consisted of a learning phase and a test phase. The learning phase was administered to allow the participants to learn and practice gestures. Post learning, the participants were asked to recall all the gestures they could remember during the test phase. Instructions for each stage were given prior to their beginning. To gather further insights about the mental mapping the participants made with regards to the color-coding, at end of the experiment, using our post-test questionnaire, we asked our color-coded gesture group participants if the color-coding had meant anything to them and if it had helped them in any way to remember the gestures during the test phase.

As part of more generic instructions, we explained to the participants that the Microsoft Surface is sensitive to recognizing hover, and hence while interacting it would be better for them to keep their finger approximately perpendicular to the display. We also mentioned to them that they were free to quit at any point during the experiment.

Our current prototype does not consist of a gesture recognition software and therefore to judge the accuracy of the gesture performed the entire session was video recorded. Using the video recording we collected two types of data: **(a)** total time taken during test phase, **(b)** the number of correct gestures performed and **(c)** qualitative data from group A regarding their thoughts about color-coding gestures.

Learning Phase

During the learning phase each participant was shown eight single touch gestures on the Microsoft Surface. The gestures presented during the learning phase were shown either completely in black (for group B - no color), or were rendered with four colors based on direction (for group A - color) as seen in Figure 1. To eliminate the effects of order we created twenty four random gesture orders to be used during the study [17]. The gestures appeared one by one on the grid and were shown using animation sequences of the gesture strokes. The gesture display order was controlled by the experimenter using a keyboard.

Each gesture was visible on the grid for 30 seconds and during this time the participant was free to practice the gesture as many times as they liked (Figure 3). Prior to playing the animations, participants were explained that the size or scale of the gesture did not matter, but the direction was important. The participants were made aware at this stage that they had to recall the same gestures during the test phase.

During the learning phase we saw different strategies being employed by the participants. While some participants created the same shape several times on different regions of the screen as seen in Figure 3a, some preferred to redraw over the original gesture visualization multiple times as seen in Figure 3b. At the end of the 30 seconds time frame the screen was cleared and the experimenter would select the next gesture to be shown on the display. The test phase ended with all of the eight gestures being shown.

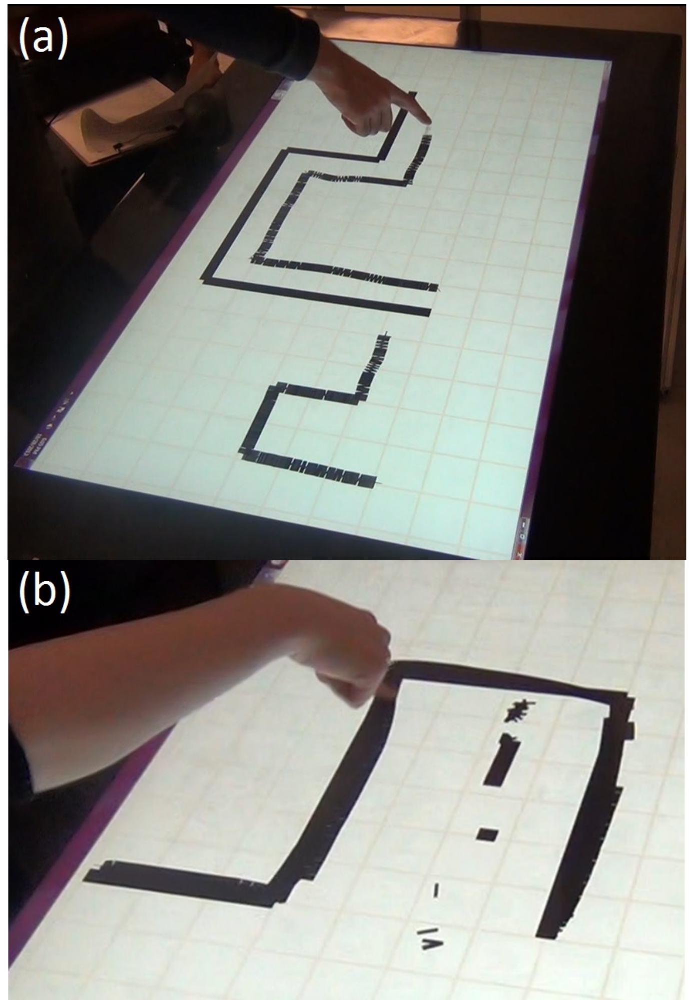

Figure 3. Learning phase.

Test Phase

The test phase was conducted post the learning phase. During the test phase the participant was asked to recall all the gestures they could remember and redraw on the grid. There was no set time limit to perform this task. The participants was allowed to take as long as they liked to recall the gestures. Figure 4 shows the result from one of the test phases. The test phase was stopped when the participant told the experimenter that they wanted to stop.

Data Analysis

As mentioned previously, the entire session was video recorded. For each of our conditions, A - color group and B - no color group, we collected the total number of correctly performed gestures per participant and also the amount of time taken to perform those correct gestures. To compare these

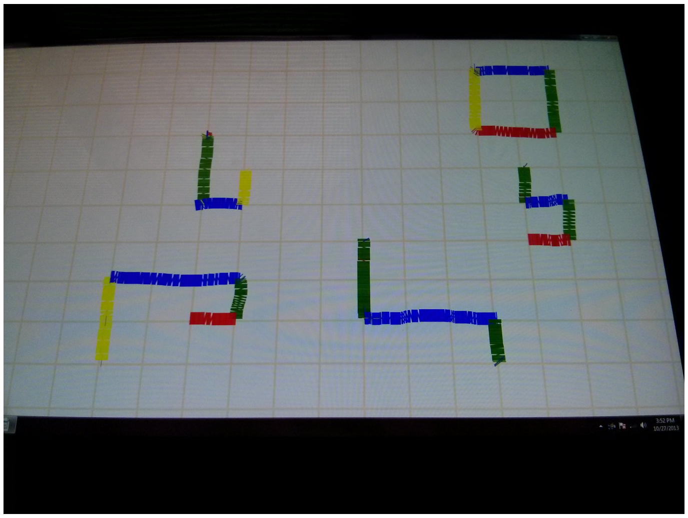

Figure 4. Example test phase output.

dependent variables and study the effect of color-coding on gestural memory we conducted t-test at significance level of .05.

Limitations

Some of the limitations of our method are as follows:

(a) Between subject study design was chosen to avoid learning effects. However, one limitation of this method is that we have no measure of how the same participant would have performed under the other condition. Thus, limiting us from getting a clear picture of how our participants from the no-color group would perform using color-coding as a teaching tool. On the other hand, conducting a within subject study design would have given rise to learning effect. If this was counterbalanced using different set of gestures, then it would be difficult to understand if the type of gesture had any effect on performance.

(b) Restricted gesture set is yet another limitation of our method. Firstly, the constraint of four strokes single touch gestures limits the number of gestures that can be created, and also the resultant gestures will be very similar. Secondly, the results of our study cannot be generalized beyond this subset and it may happen that different results could be obtained if we had considered different types of gestures such as single touch, bi-manual gestures etc. However, with different categories of gestures we increase the number of independent variables and it becomes difficult to identify if color-coding has an impact or if the gestures themselves have an impact on the results.

(c) The mapping of color to a gesture can be done in several ways. Either a gesture can be completely colored, thus resulting in each gesture having a different color, or alternatively, as done in this experiment, we can incorporate the color to represent the directions in a gesture. However, we believe the style of mapping may also impact the results and therefore our opted color mapping may also have restricted our results.

(d) Lastly, the gesture animation is also a limitation of this experiment. The strokes were displayed as complete elements and did not appear as if someone was drawing the gesture on the grid. Although we did not observe any of our participants struggling to get the order of the strokes during the practice session, it may have been more effective to have a better animation or rendering style.

RESULTS

Table 1 and Table 2 present the collected data for the two dependent variables of this experiment - number of correctly performed gestures and recall rate, respectively. As can be observed from Table 1 in both the groups, six out of eight was the maximum number of correctly performed gestures, with a least of two out of eight and one out of eight gestures being performed correctly in the color and no color groups. Conducting a t-test on this table revealed that there is no significant differences to be observed between the two conditions. The obtained two-sample t-Test assuming equal variances values for Table 1 are as follows: t(22)=1.42, p=0.05, critical value = 2.07. The mean value for color group is 4, and that for no-color group is 3.08. The difference in variance is 0.26. Since t is less than the critical value for the dependent variable correct number of gestures, the hypothesis cannot be rejected for this condition. In other words, no statistical differences are observed between color and no color group in terms of the number of correct gestures identified by the two set of participants.

From Table 2 it can be observed that the least time taken during the test phase by the color group to identify five gestures is 18.6 seconds, compared to 11.75 seconds to identify four gestures in the no-color group. The maximum time taken is 125 seconds to identify two gestures for the color group and 103.5 seconds to identify two gestures for the no-color group. We can also observe that the average time to recognize the maximum number of correct gestures (6 out of 8 in both groups) in the color group is 35.245 seconds, compared to 48.33 seconds in the no color group. Conducting a t-test for Table 2 we obtained the following: t(22)= 0.41, p=0.05, critical value = 2.07. Due to the t value being less than the critical value, the hypothesis cannot be rejected for the dependent variable recall rate. Hence, overall we can conclude that color coding has no effect on the learning of single touch gestures consisting of four strokes.

Figure 5 shows the distribution of the correct number of gestures identified by both the groups. The maximum success rate in the color group as can be observed in Figure 5 is that 33% (4 out of 12) participants identified 62.5% (5 out of 8) of the gestures correctly, compared to 50% participants identifying 50% of the gestures correctly in the no-color group.

Figure 6 shows the distribution of the number of participants who got a particular gesture correct. The gesture order in the y-axis is the same as shown in Figure 1. A t-test on this data resulted in: t(14)=0.99, p=0.05, critical value = 2.14. Although, no significant difference is seen between the gestures, it is interesting to observe that gesture 6, that resembles a square, a simple shape, was correctly reproduced by 9 out of 12 (75%) participants from the color group, compared to 4 out of 12 (33%) participants in the case of no-color group.

Table 1. Dependent Variable - Correct number of gestures

Participant	Color	No Color
1	2	6
2	5	4
3	3	2
4	3	4
5	5	4
6	6	1
7	4	1
8	5	1
9	2	4
10	5	4
11	6	2
12	2	4

Table 2. Dependent Variable - Recall rate (in seconds)

Participant	Color	No Color
1	124.5	48.33
2	30	21.25
3	74	62
4	24.33	23
5	18.6	22.5
6	28.83	79
7	45.75	44
8	25.8	56
9	125	11.75
10	19.2	50
11	41.66	103.5
12	54	24.75

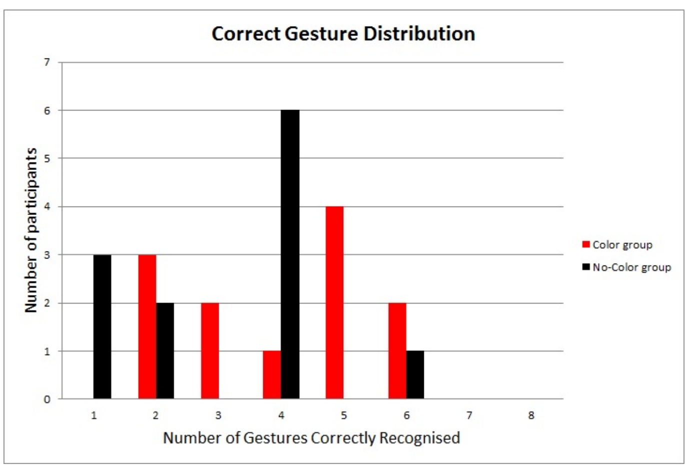

Figure 5. Distribution of the number of participants with respect to the number of correctly recalled gesture.

DISCUSSION

Contrary to what we expected, there were no differences to learning single touch gestures using color coding. In the sections below we present an interpretation to our observed results and also a set of discussion points that we believe can be useful to inform such experiments in the future.

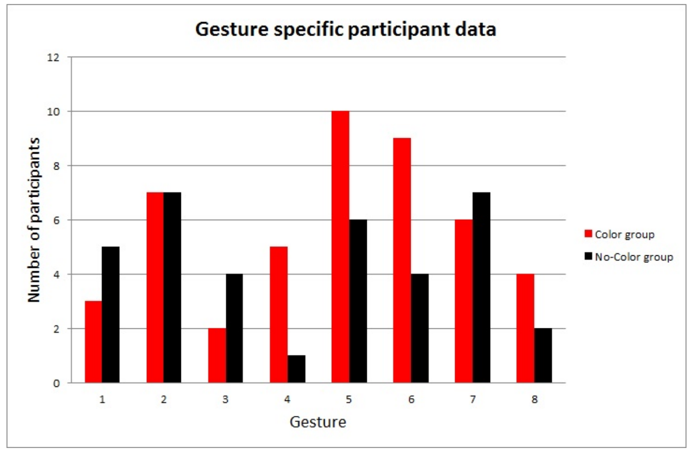

Figure 6. Gesture specific participant data.

Interpretation of results

It can be observed from Table 1 that the mean success rate for the color condition is 50%, compared to a mean success rate of 38.5% for the no-color group. From Table 2 we can observe that the average time to recognize 6 out of 8 gestures (highest number of gestures correctly identified in both groups) in the color group was slightly faster than that in the no-color group. Yet statistically there were no significant differences to be found using the t-test. In other words the null hypothesis cannot be rejected with regards to teaching single touch gestures using color-coding. However, due to the controlled nature of the experiment and the restricted set of gestures used in the study, the generalizability of these results is low. Some possible reasons for the null hypothesis could have stemmed from causes such as low exposure times (30 seconds) during the learning phase, very similar gestures or lack of task context. In the section below we summarize some of our high level observations to reason the possibilities.

Implications

We propose the following implications that can be considered for studying the effect of color as a tool for learning new and advanced gestures:

Blending color with gesture

Color coding has seen to be beneficial for learning mostly in cases where the color can be blended within the context of the learning [10]. However, blending color within the content being taught can be difficult. Mapping color to the entity being taught can be done in several ways. The number of colors chosen may also impact the results of the experiment. In this experiment the assumption was that since direction is one of the important components to a gesture, mapping color to reflect upon the directions of the gesture stroke can perhaps help remembering the gesture, unlike the no color case, where all the lines are represented by a single color. However, it was surprising that during the experiment most of participants in the color group did not associate that the color of gesture strokes was representative of directions such as up, down, left and right, *"I was going to ask (about color-coding). It makes sense now, but I would have never seen it. I would have just thought they are random basically."*.

The choice of mapping color to gesture stroke direction also arose from some previously conducted tests wherein we had considered the case of mapping each gesture (i.e. whole gesture) to a different color. However, when this scenario was evaluated with one of our colleagues, it was observed that the emphasis in this case shifted to the range of colors rather then the gesture, i.e. the participant could remember the colors but not the gesture. However, since the effect of color on gestural memory cannot be completely rejected, it maybe worth to investigate other mapping techniques, such as mapping color to the context in which the gesture can be used, or perhaps use color to hint at the direction the gesture should continue.

Gestural memory versus visual memory

Color coding has seen to be an effective teaching tool to improve visual memory [3, 6, 9, 10, 16]. However, gestural memory has two components - visual and motion. In order to teach a gesture it would be important to device techniques that will emphasize both these aspects. This thought was also observed to be echoed by our participants who mentioned that while the final shape (*"people remember the final shape"*) of the gesture was important for remembering the gesture, the direction was also an important aspect that they constantly paid attention too (*"direction was more important than color to me"*). This design implication is also important from the point of view of running an experiment, where it will be important to distinguish between these two contributing factors to better understand the generalizability and reliability of the results obtained.

Effect of color on cognition

When designing experiments such as these, it is important to reflect upon the effect of color on one's cognition load. While some of our participants mentioned that color was a source of help and it allowed them to identify the directions of the gesture strokes, they also mentioned that it also added to confusion as they learnt more gestures. This is perhaps a hint against the use of multiple colors for representing gestures. The shift from remembering the color versus the gesture, is perhaps a competing factor that needs to be handled before color can be used as a means for teaching a gesture.

Effect of gesture scale and shape

From the remarks of our participants post the experiment, it was observed that the scale and shape of the gesture also has an impact on learning. During the learning phase the gesture span consisted of six blocks of the grid for the longest strokes and four blocks of the grid to represent the shortest stroke. Although the participants were previously explained that the size of the gesture has no impact in this experiment, it was observed that some participants had a conflict between remembering the size of the gesture versus remembering the actual gesture as a whole, *"scale is a problem. I spent more time calculating the blocks (grid blocks) and then forgot the gesture at the end of it."*.

It was also observed by the comments of some of our participants that the shape of the gesture also had an effect on learning the gestures. While gestures 1 to 4 were considered to be very similar and confusing (Figure 6), many of our participants mentioned that they could remember gestures 5 to 8 from Figure1 because their shapes resembled the letter 'b', 'O', inverted 'P' and 'G'. However, during the calculation of the number of correctly performed gestures, we noticed that many times the final shape was remembered, more specifically in the case of 'O' or square shaped gesture , but the gesture direction (i.e. clockwise or anticlockwise) was incorrect both in the case of color and no color condition.

Effect of number of gestures, gesture composition and type of gesture

The number of gestures, the gesture stroke composition and the type of gesture (i.e. single touch, bi-manual or multi-touch) being taught will also have an impact on the learning. The decision to use eight gestures in total was made using some early preliminary tests that was run between the experimenters. The idea was to reach a number, where the designers of the gesture could remember atleast 50% of the gestures being tested.

The composition of the gesture was also obtained in a similar manner. Using one, two or three stroke gestures limits the number of gestures that can created and at the same time, makes the experiment easy. Four stroke gestures on the other hand allow a reasonable set of gestures to be created and also allows for complexity in testing.

The experiment may also be interesting to extend for scenarios where a class of gestures, such as, single touch, bi-manual, three finger and five finger gestures an be tested. Perhaps the test could be repeated for existing gesture sets to observe how it fairs in a practical scenario.

Effect of context

One of the limitations of our experiment was the lack of context. Touch gestures are often used within an interaction context and this allows us to mentally map them to an action to be performed. For instance, slide to pan or tap to select. In this experiment, on a high level all the gestures were merely some shapes that the participants had to remember. While this allowed us to focus on understanding the effect of color on gesture, it also lessened our ability to explore other aspects that are important to learning a gesture.

Future Work

We believe two of the main limitations of this exploration is the restricted gesture set and the lack of task context for using the gestures. It would be interesting to repeat the experiment by varying these factors. It would also be interesting to explore the practical exploration of this mapping using a gesture set of an available device and to identify if learning gestures can increase the use of all types of gestures supported by the device.

Secondly it would also be interesting to explore if color coding would cause any effect on learning if the gestures were tied to some task context. Currently in our prototype, from a high level, the gestures are merely symbols that have no context. However, the challenge here would be to identify if the recall was really due to color or was it because of the task context.

Lastly it would also be important to implement a gesture recognition system to better estimate the accuracy of the gesture being re-drawn to better understand where feedbacks can be incorporated to help learning.

CONCLUSION

This paper presents a controlled experiment that explored the effect of color coding on gestural memory. The experiment detailed presents the results from the pilot stage of the controlled experiment, conducted with twenty four participants using a between-subject design. We examined the success rate and recall rate of eight single touch, four stroke, gestures using the two conditions - gestures color coded by direction and gestures coded using a single color black. Contrary to our initial hypothesis, conducting a t-test on the collected results of the pilot test reported that there was no significant results to be observed in both the success rate and recall rate. To reason our findings, we present six possible implications to consider while designing such experiments.

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