A 3D Interface for Selecting Household Paint Colors

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Abstract

Commercially available tools for searching collections of paint colors are critically examined and a new computer interface for selecting household paint colors is proposed. The new system is organized according to a perceptual color space and uses modeless, constrained, in-place, 3D interaction. Two user studies are performed to evaluate this system and the results are discussed. These studies demonstrate that, with enough training, our system is faster and at least as accurate as current color search tools. The results suggest that the tool could be beneficial to properly trained design professionals. Users also report a favorable impression of our system over the current tools.

Introduction

In this paper we present a new, computer-based interface for examining and searching through collections of paint colors, one that acknowledges the existing tools (color cards) and connects back to them physically. This new system, called the Color Navigator, is rooted in perceptual color organization and affords simple, direct 3D interaction. We developed this tool as an alternative to the standard fan decks of color cards used by almost all major paint manufacturers and we evaluated its effectiveness in comparison to these decks. We found that the Color Navigator can be faster than the fan deck and received a favorable evaluation by users over this traditional tool.

Background

Current Paint Selection

For quality control purposes, most paint manufacturers will pre-formulate all the colors that are achievable with their set of bases and tints. Tints are combined in certain proportions to achieve different pure hues and are added to the bases in increasing amounts to create shades of that color. These related shades are the basis for multi-color cards which present a single ‘hue’ (roughly speaking) in several levels of lightness, attributable to increasing amounts of tint. These multi-color cards are often presented on large racks (see Figure 1), or bound together in a single deck of cards that can fan out and be easily transported (see Figure 3).

It is informative to plot the colors for a single fan deck card in CIE L*a*b* color space (and its polar equivalent, CIE LCH_{ab}). For more on these colors spaces, see [6, 11]. The locus for these colors is not a straight line and the colors do not have a constant L* value, a constant chroma, or a constant hue. This means that CIE Lightness, Chroma, and Hue are all changing simultaneously on a single card (see Figure 2). This curved trajectory is the result of the tinting process and, while each color card follows a different path, the example shown is typical of all fan deck cards.

Figure 1. *Searching through the color cards in a display rack.*

Problem Statement and Requirements

After talking with experts in the paint industry and interior designers helping customers in a paint store, the following problem was identified:

> Given a collection of thousands of color choices, what is the best way to locate individual colors that are good candidates to match a specific or abstract target?

Here, the ‘target’ may be either a real artifact with some or all of the visual properties desired or just an abstract concept of a color that a customer has in mind.

This problem led to the following requirements for a successful interface:

Similar Proximity *Colors that are similar to each other should be physically close to one another.*

This is a natural requirement for any search problem. Because of the non-perceptual nature of the color cards, this requirement is not met in the fan deck or color card rack where multiple, separate groups of related colors are noticeable (see Figure 3). This could lead the user to miss some good candidates for their target.

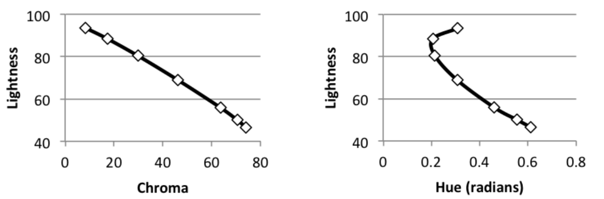

Figure 2. *A single color card plotting CIE Lightness against CIE Chroma (left) and CIE Lightness against CIE Hue (right) (based on CIE L*a*b* space). Note how the card's locus changes in all three dimensions at once.*

Color Perception *The color collection should map to the commonly accepted perceptual color dimensions of hue, chroma, and lightness*

This requirement should further ease searching as it leverages an instinctive perceptual structure. The color cards give the appearance of changing mostly in lightness but this is not the case. This can mislead a naïve user as these multi-dimensional perceptual changes could affect their perception of color similarity.

Direct Comparison *To facilitate direct comparisons with a target based on an artifact, the interface should make it possible to place the artifact next to the colors in the color collection.*

While it is easy to compare an artifact with a single color or a color card, it is difficult, if not impossible, to determine the artifact's relation to the collection as a whole. This is an important concept as customers often envision a target color that is related to but slightly different from the artifact chosen. Searching for proper alternatives requires a broader context than a single color card.

Current Tools *In support of users already familiar with the current tools, the interface must not completely abandon the traditional color cards.*

Given the financial investment that paint companies have already made in their fan decks, simply rearranging the colors on the existing cards was not an option. In addition, those working in the paint industry emphasized their experience and comfort with the cards.

Color Selection and 3D Interaction

The problem statement and requirements led to the development of a 3D computer graphic interface. Due to the requirement to incorporate current tools the cards themselves had to be part of the final solution. However, supporting color perception suggested the use of a color space with familiar perceptual dimensions such as CIE LCH_{ab} space. While many color selection interfaces have been created using 2D projections of three dimensional hue, saturation, and brightness color spaces (see [3, 5, 9]), this did not meet our needs because each color card varied simultaneously in all three perceptual color dimensions. The cards could not easily be unwrapped, separated, and unambiguously projected onto a 2D surface.

Figure 3. *A pair of color card fan decks and some example multi-color cards showing multiple shades of a single hue. Note the similar hues separated by physical distance in the fan decks.*

In developing our interface we followed the guidelines of [1, 2, 10] for developing 3D interaction techniques that are similar to existing techniques in 3D CAD and modeling tools.

The Color Navigator

In this section, we describe our alternative color search tool called the Color Navigator; an interactive visualization of the color card fan deck.

Visualizing the Fan Deck

The Color Navigator is a visualization of the fan deck in CIE LCH_{ab} space (see Figure 4). Each card is plotted as a strand with separate squares of color along it so that it looks like a multi-color card. The strands are created by fitting a curve to the LCH values of the colors on each card. We chose a 2nd degree polynomial fit as it does a good job of preserving the location of the colors in CIE LCH_{ab} space while eliminating the oscillations and high order curvature found in other fittings. The strands are placed above a circular platform with an embedded hue rainbow. This grounds the visualization and guides the user to a particular point in the spectrum.

To support the direct comparison requirement, our system can plot additional colors provided in the LCH representation (available from in-store scanners). This scanned color is drawn as a small sphere or, for better comparison with the cards, a flat chip (see Figures 6 and 7). The sample color is placed at the coordinates indicated by it's LCH values putting the sample directly in the context of the full color collection where physical distance will be a good approximation of color similarity. The scanned color is drawn sitting on top of a small pedestal that extends down to the circular platform. This helps the user perceive the location of the object along the projected depth dimension, something that can be difficult without the help of expensive stereoscopic rendering or other depth cues like shadows that would adversely interfere with perception of the colors.

As with any color seen on a display device or observed under a viewing illuminant, there are colorimetric and environmental influences that must be addressed. For the computer display, a neutral background with an abstract design was chosen so that it

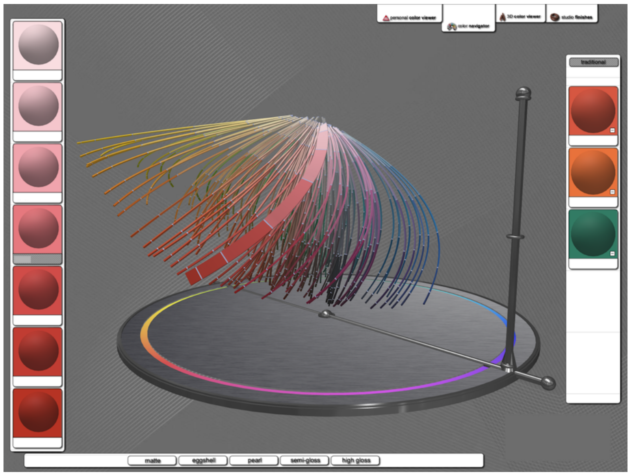

Figure 4. *The Color Navigator interface. In the center is the color platform with the currently selected card (larger) shown to the left and the favorites palette to the right.*

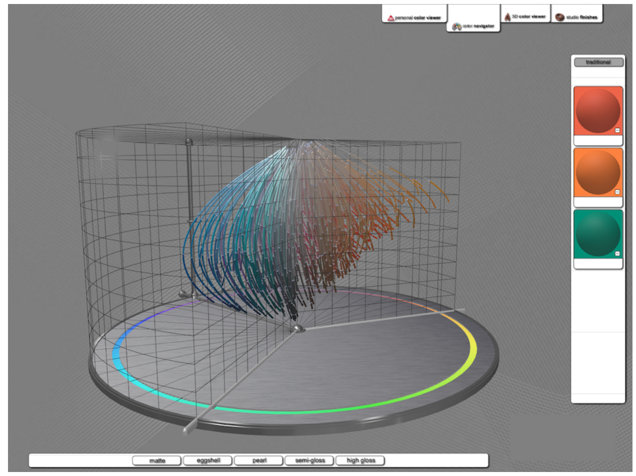

Figure 5. *Using the basket with a very crowded collection that obscures interior colors and looks cluttered.*

would contrast with the visualization structurally but not in color, reducing the effects of simultaneous contrast. A commercially available calibration device was used to measure monitor chromaticity and map the collection to the specific monitor in use. For this initial work, the calibration of the monitors and the illumination of the fan deck were held constant to minimize their influence and reduce the complexity of the system and the user study. While different illuminants will change the CIE L*a*b* coordinates of the colors and effect our visualization, we chose to use a single illuminant (D65 daylight) for this work and leave the importance of this factor for future study.

Interaction

The color cards initially appear thin with a square cross-section to minimize obstruction of interior cards. When the mouse is above a color card it expands to a rectangular cross-section similar to the dimensions of a physical card from the fan deck. The card under the mouse is also drawn as part of the interface overlay to the left side of the color platform. On this larger card at the side, the current color under the mouse is highlighted and tracks the user's movement. To the right of the color platform is an area where the user can add and remove colors for consideration separate from the collection. We call this the favorites palette.

To control the view of the color platform we provide simple, constrained controls for rotation, zoom and translation. Rotation behaves like a 'turntable' spinning the color platform around its central L axis by dragging with the left mouse button. The camera can be zoomed in and out with the mouse's scroll wheel or by dragging with the center mouse button. The user can also shift the color platform around the screen by dragging with the right mouse button.

To support the task in our user study, we allow the user to move the color target pedestal. It moves in the C and H dimensions by grabbing the pedestal and dragging it around the platform. It can be moved along the L dimension by grabbing the color at the top of the pedestal and dragging up or down.

Data Obstruction and Clutter

To deal with obstruction and clutter in the visualization, the system provides a novel set of controls collectively called *the basket* (see Figure 5).

The basket defines limits in each of the perceptual dimensions of Lightness, Chroma and Hue. Any cards that are inside those limits are drawn and any that are outside are hidden. If a card is partially inside the basket, only the colors that fall inside are drawn while the rest of the card is indicated by a thin grey line. This provides some context to the shape and location of the entire card to the user.

Manipulators are provided for setting each of the basket limits (see Figure 7). These controls sit on the platform itself (or for the lightness dimension, on a pillar rising out of the platform) and are adjusted by directly grabbing and dragging them around the space. Whenever the user is adjusting the limits a wire grid is drawn to visualize the basket volume providing instant and continuous feedback.

Adjusting the basket affords hiding of the exterior strands and access to interior colors mitigating the problem of obstruction. The user can also eliminate colors that are of no interest and decrease the volume of information on the screen to afford zoom-

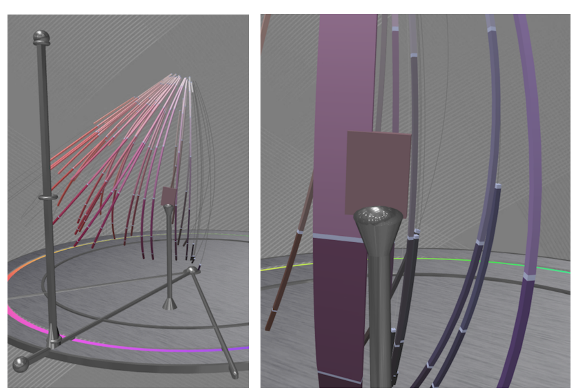

Figure 6. *The Color Navigator displaying the target search color for the multi-color search task.*

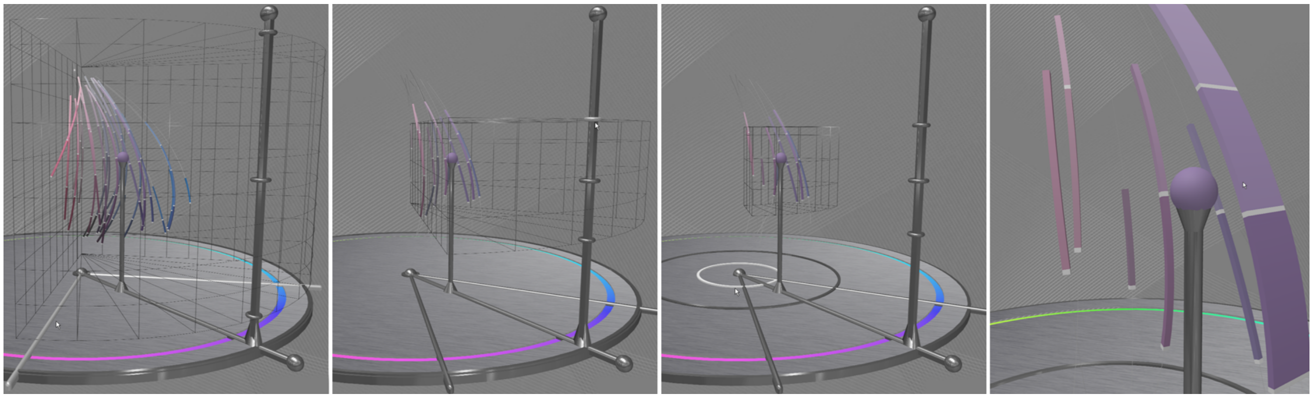

Figure 7. *Using the basket controls to isolate a small precise section of color for comparison. The sphere represents a target color (possibly scanned). From left to right: Limiting hue, lightness and chroma then zoomed in close.*

ing into a small area where colors can be critically examined and compared.

All interaction with the color navigator and the basket is consistent with the guidelines laid out by John Schrag in [10].

User Studies

To evaluate the effectiveness of our interface versus the traditional fan deck we conducted two user studies; one without any training in color perception or 3D interaction and the second with training in both. For both studies we were testing the following hypotheses:

- The Color Navigator can be used faster than the fan deck for search tasks.
- Users will choose colors using the Color Navigator that are at least as similar to the target as those chosen with the fan deck.

For the second hypothesis we compute 'similarity' using euclidian distance in CIE L*a*b* space; a simple form of the Delta E metric (CIE76, ΔE^*_{ab}) where a value of 2.3 corresponds to a just noticeable difference [8].

Search Task

With a real-world color search process in mind, we defined the following task (we call it the multi-color search task):

> The subject is given a target color (not present in their collection) and asked to search for and identify the five colors that are as similar as possible to the target color.

Participants using the fan deck were given a color card containing a single, unidentified color as the target and provided pen and paper for note taking and to indicate their answer. Participants using the Color Navigator were shown the target as a chip on top of the color target pedestal (see Figure 6). They were instructed to utilize the favorites palette to 'take notes' and indicate their final answer. Each subject performed three to four iterations of this task. We recorded the time it took to complete the task and the five colors identified in the search.

Subjects using the fan deck were given a brief introduction to its organization and allowed to experiment with the deck prior to starting the task. Subjects using the Color Navigator were shown all the interaction available to set their view and control the basket and were given some simple tasks to perform to encourage using all these controls prior to starting trials. They were also shown the color target pedestal and its controls and allowed several preliminary task trials to ensure they were comfortable with the interface.

All subjects were screened for color blindness using the color plates from the Dvorine Testing Charts [4].

Tests Performed Without Extra Training

Over the course of two Saturdays, 32 subjects were recruited (30 female) from a local paint store either via their newsletter or on the store floor. Only 2 subjects identified themselves as being designers or in the design field. Only 1 participant reported prior experience with 3D computer interfaces. Each subject used only one of the two tools (either the fan deck or the Color Navigator). The participants were divided evenly among these tools. Subjects were not compensated.

Results

Independent samples t-tests were performed to compare both time and accuracy using the fan deck versus the Color Navigator. We looked at each of three different color targets separately and then with all trials pooled in one.

With respect to search time (in minutes), with the trials pooled there was significant difference in the scores for the fan deck ($M = 4.37$ mins, $SD = 1.925$) and the Color Navigator ($M = 5.51$ mins, $SD = 2.140$); $t(44.022) = -1.912$, $p = 0.0312$. Only one of the individual color targets had a significant difference in scores and showed similar results, the other two were not significant by themselves. This is a negative result that contradicts our first hypothesis and indicates that the fan deck was faster than the Color Navigator.

With respect to accuracy (in Delta E), with the trials pooled there was significant difference in the scores for the fan deck ($M = 14.39\ \Delta E$, $SD = 6.95$) and the Color Navigator ($M = 18.68\ \Delta E$, $SD = 5.37$); $t(43.079) = -2.377$, $p = 0.022$. Again, only one of the individual color targets had a significant difference in scores with similar results. This is also a negative result that contradicts our second hypothesis and indicates that the Color Navigator was not as accurate as the fan deck (the data summary shows that it

Figure 8. *Box and whisker plots of the 5 number summary statistics (minimum, first quartile, median, third quartile and maximum) for completion times (left) and accuracies (right) in the first study. The circles are outliers and are beyond 1.5 times the inner quartile range.*

was in fact less accurate). The data is summarized in Figure 8.

Tests Performed With Extra Training

Over the course of one week, 10 subjects were recruited (2 female) from our university using signs and interviews during passing periods. 7 subjects reported some significant prior 3D interaction experience. 2 subjects reported working in a design discipline (interior design and architecture). Unlike the previous study, all users were asked to perform the task using both the fan deck and the Color Navigator. To eliminate ordering effects, half the participants used the deck first while the other half started with the Color Navigator. Subjects were compensated with a $15 gift card.

Extra Training

In this study, all subjects were trained in the following areas:

- Munsell's color system and perceptual color.
- general 3D interaction using Google SketchUp.
- the Color Navigator interface controls.
- the relationship between Munsell's system and the Color Navigator.

The first phase of training was done with the Munsell Student Color Set [7]. Subjects were asked to reconstruct the initial hue, value and chroma page using the provided paint chips as well as the value and chroma page for the 5BG hue. This initial color training was done immediately after screening for color blindness and prior to any trials. All other training was only done prior to searching with the Color Navigator.

The second phase of training consisted of two simple tasks using Google SketchUp (see Figures 10 and 11). It allowed us both to train the subjects that were not as familiar in 3D interaction concepts and to assess each subject's familiarity with a 3D interface in general. They were trained in 3D object movement and rotation.

Results

The same t-tests as the first study were performed to compare time and accuracy. However, this time, since both samples were the same, we used a paired samples t-test.

With respect to search time (in minutes), with the trials pooled there was significant difference in the scores for the fan deck ($M = 4.41$ mins, $SD = 1.724$) and the Color Navigator ($M = 3.20$ mins, $SD = 1.46$); $t(29) = 3.8404$, $p = 0.000308$. All but one of the individual color targets also had a significant difference in scores and showed similar results. This is a positive result that agrees with our first hypothesis and indicates that the fan deck was slower than the Color Navigator.

With respect to accuracy (in Delta E), with the trials pooled there was not a significant difference in the scores for the fan deck ($M = 12.140\ \Delta E$, $SD = 3.880$) and the Color Navigator ($M = 13.653\ \Delta E$, $SD = 4.538$); $t(29) = -1.313$, $p = 0.1995$. Also, two of the individual color targets did not have a significant difference in scores (although one of the more difficult trials, 'H,' did). This is also a positive result that supports our second hypothesis and indicates that the Color Navigator was at least as accurate as the fan deck. The data is summarized in Figure 9. Complete t-test results are in Table 1.

Discussion

The different results between the two studies show that successful use of the Color Navigator requires facility with 3D interfaces and knowledge of traditional LCH color organization schemes. When these two conditions were met our hypotheses were confirmed. Observing the subjects as they performed the extra training tasks (and analysis of the times that were recorded for these tasks) showed considerable variance. Some subjects found one or both of these tasks easy while others struggled. This suggests that the new training regimen was beneficial in overcoming these confounding factors.

The time savings provided by the Color Navigator would be beneficial to individuals who make a significant number of color selections throughout the week (such as design professionals and paint store color stylists). These professionals may be willing to invest the effort necessary to learn how to use a 3D interface (if they don't already know how to do so), and are likely to already understand LCH color organization schemes.

It is worth noting that in the study with extra training, both of the two design students who participated had prior experience with SketchUp and had previously taken a color theory course that utilized the Munsell Student Color Set [7] in some capacity. This suggests that today's design professionals may already have the experience necessary to effectively interact with the Color Navigator.

Conclusions and Future Work

The Color Navigator is an interface that appears to be useful to a specialized audience. It could save time for interior designers or architects who must make hundreds of color selections throughout a typical month. This group is also likely to use other computer graphic tools to visualize their interior spaces and buildings. The Color Navigator allows them to put the color fan deck

Figure 9. *Box and whisker plots of the 5 number summary statistics for completion times (left) and accuracies (right) in the second user study.*

	t-score	*p-value*	*Mean of Diffs.*
All	$t(29) = 3.8404$	0.0003	1.24
'B'	$t(9) = 1.6106$	0.0709	0.60
'H'	$t(9) = 4.4237$	0.0008	1.81
'F'	$t(9) = 1.9208$	0.04347	1.21
All	$t(29) = -1.313$	0.1995	-1.51
'B'	$t(9) = -1.3361$	0.2143	-1.44
'H'	$t(9) = -3.8517$	0.0039	-3.05
'F'	$t(9) = -0.0621$	0.9519	-0.05

Table 1. Data from the paired t-tests comparing time (top) and accuracy (bottom) in the second study.

aside just as computer based rendering systems permit them to avoid the use of drafting tools. It is another step along the way to virtualizing the design process in traditional fields of design.

While it was not measured in any of our experiments, it should also be pointed out that the Color Navigator made a favorable impression on almost every user. It was described as more compelling and fun than the fan deck and 90% of participants in the second study said they would use the Color Navigator again if given the option, either by itself or in conjunction with the fan deck.

References

[1] Eric Allan Bier. Skitters and jacks: interactive 3d positioning tools. In *Proceedings of the 1986 workshop on Interactive 3D graphics*, I3D '86, pages 183–196, New York, NY, USA, 1987. ACM.

[2] Michael Chen, S. Joy Mountford, and Abigail Sellen. A study in interactive 3-d rotation using 2-d control devices. In *Proceedings of the 15th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '88, pages 121–129, New York, NY, USA, 1988. ACM.

[3] Sarah A. Douglas and Arthur E. Kirkpatrick. Model and representation: the effect of visual feedback on human performance in a color picker interface. *ACM Trans. Graph.*, 18:96–127, April 1999.

[4] Israel Dvorine. *Dvorine color perception testing charts*. The Waverly press, inc, Baltimore, Md, 1944.

[5] George H. Joblove and Donald Greenberg. Color spaces for computer graphics. In *Proceedings of the 5th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '78, pages 20–25, New York, NY, USA, 1978. ACM.

[6] Deane B. Judd and Günter Wyszecki. *Color in business, science, and industry*. John Wiley & Sons, New York, NY, 1963.

[7] Jim Long and Joy Turner Luke. The new munsell student color set, 2001.

[8] Gaurav Sharma, editor. *Digital Color Imaging Handbook*. CRC Press, Hoboken, 2002.

[9] Alvy Ray Smith. Color gamut transform pairs. In *Proceedings of the 5th annual conference on Computer graphics and interactive techniques*, SIGGRAPH '78, pages 12–19, New York, NY, USA, 1978. ACM.

[10] Paul S. Strauss, Paul Isaacs, and John Schrag. Course 20: Design and implementation of direct manipulation in 3d. In *SIGGRAPH 2002 Course Notes*. ACM, 2002.

[11] Günter Wyszecki and Walter S. Stiles. *Color science: concepts and methods, quantitative data and formulas*. John Wiley & Sons, New York, NY, 1967.

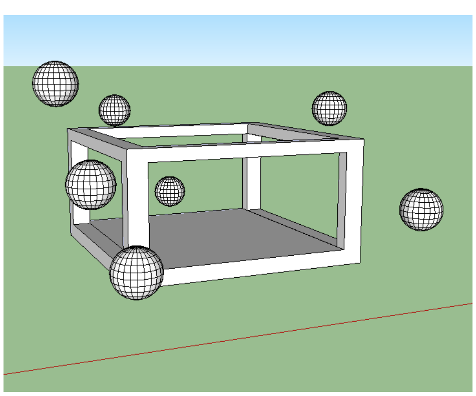

Figure 10. *The object movement training task using Google SketchUp.*

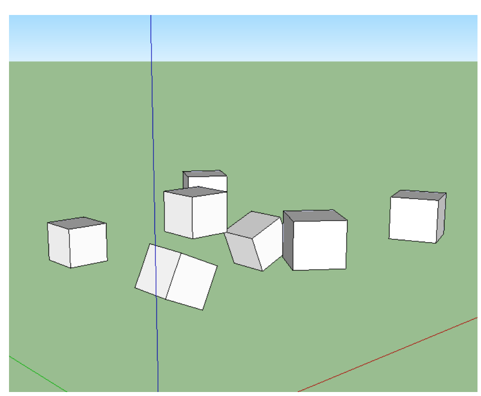

Figure 11. *The object rotation training task using Google SketchUp.*