Original Article

Visibility based on eye movement analysis to cardinal direction

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Abstract

The purpose of this paper is to find out what the eyes focus on when determining which way is north. Projects that required identifying north were assigned, then the subjects' eye movements were followed with an eye movement tracker, and their tracks and the amount of time they paused at each interval were determined. Results showed that the reaction time became faster as the number of directions the arrow pointed toward decreased for the four types of compass roses. Furthermore, for each compass rose, the subjects' reaction time shortened where the directional point the letter "N" (for north) was present. As for eye movement, the eyes tended to move toward the edges of the compass, on letters and at intersecting points. The subjects' eyes focused on "N" the longest. With regards to instructions by letter, those with just an "N" on the compass rose elicited a narrower range of movement in the eyes than for those indicating the four cardinal directions, north, east, south and west. Without a letter designation, the eye movement range tended to be more scattered.

Key words

cardinal direction, eye movement, reaction time, fixation time, visibility

1. Introduction

Pictograms and direction symbols have been important sources of guidance throughout the ages. Surveys and semantic differential (SD) techniques have been applied to design signs and pictograms that are beautiful and convey a positive impression (Yamamoto et al., 2003). For example, Chen et. al.(1999) used questionnaires and SD techniques to measure attitudes toward the design of a directional indicator, and in the process revealed that in order to create one with an effective visual transmission it had to convey an impression of pleasantness and organization; this improved its chances of recognition. Additionally, Chung et.al. (2010) conducted a survey on the state of the design of a train station sign. In his study, he states that it is desirable to take into consideration the sign's visual effect on the station environment, in addition to its ability to convey information when planning a public signage system. The methods used here can help deduce the psychological responses, such as likability or impressions toward the design of a directional guide or diagram, but are not geared toward quantitative inspection. It is also difficult to add whatever considerations might be necessary with regards to information or graphic elements for the visual recognition of images.

On the other hand, with regards to attentiveness toward objects for instance, there have been numerous studies made on drawing the viewer's attention through the use of an arrow (Hashimoto et al, 2005; Hashimoto et al., 2008). The subjects' attention does not spread evenly across the surface of the graphic, but rather, as seen in Figure 1 below, travels to the edges, the boundaries, and the motion part, selectively focusing on information in front of them (Watanabe, 1965). For the directional indicators specifically for this study, the direction of the arrow, number of directions and compass needles have all been taken into consideration, creating strong visual, directional cues.

Furthermore, for emergency exit signs and other types of symbols and signage with specific instructions, being able to prompt a quick reaction is just as important as drawing the viewer's attention. Therefore, eye movements on a cardinal direction and reaction times are significant factors in designing easy-to-understand or intuitive visual directions.

The goal of a previous report was to identify important factors for the development of an intuitive cardinal direction, and conduct subjective evaluations to extract structural design elements necessary for its planning. Four types of cardinal directions were developed based on structural elements

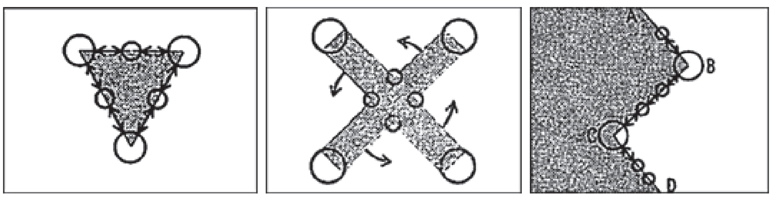

Figure 1: Example diagrams showing point of gaze dispersion on abstract directional indicators (Watanabe, 1965)

that were acquired through testing. Then, these were evaluated through pair comparison and ranking methods. Results showed that directional indicators were more often judged as easier to understand when "N" was included. Furthermore, when the pointer only pointed north, the compass was easier to understand when just "N" was present; if there were four pointers, each one pointing in the four cardinal directions, then the sign was judged as easier to understand with the direction points N, E, S and W present. However, this did not clarify where and for how long the eyes held their gaze on the diagram to ascertain directions.

This present study tracks eye movement when viewing a cardinal direction where the gaze travels, where it holds and for how long, then considered what factors were involved in creating a cardinal direction that was easy to understand.

2. Eye movement analysis on a compass rose

2.1 Experiment methods and conditions

(1) Test Subjects

The subjects who participated in the experiment were 40 university students (20 males, 20 females, average age: 23 years old). They had a 0.8 vision or higher (with contact lenses).

(2) Experiment Equipment

The Video Eye Tracker Toolbox by Cambridge Research Systems was used for the experiment. Visual stimulus was presented on a 21-inch Dell (120 Hz) monitor. The distance between the monitor and the subjects was 570mm, and a chin rest was used. The experiment was conducted under standard indoor lighting (500 lx)

(3) Stimulus Presentation

The cardinal direction used for this experiment was

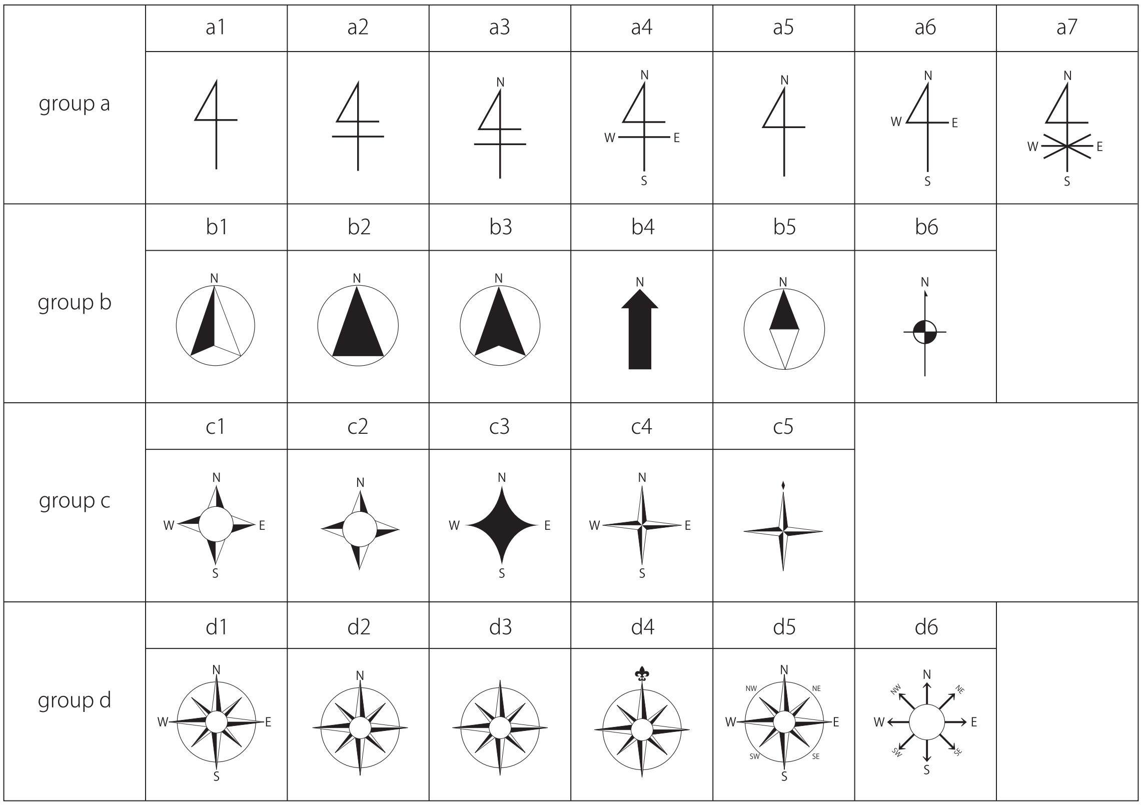

Figure 2: Stimuli used in the evaluation test

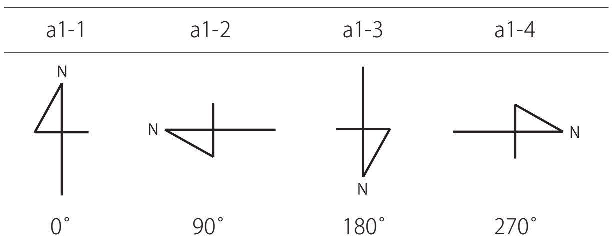

Figure 3: Directions used in the evaluation test

black and white and, as shown in Figure 2, there were 24 different types. They were the same ones used for a previous experiment to identify an easy-to-understand cardinal direction. The sizes of the indicators were: an optic angle of 7˚ x 4˚ for group (a); 7˚ x 7˚ for group (b). Samples b4 and b6, however, had optic angles of 7˚ x 4˚. group (c) had an optic angle of 7˚ x 7˚, and group (d) had an optic angle of 7˚ x 7˚. The above cardinal directions correspond respectively to (a1-1), (a1-2), (a1-3) and (a1-4), each one shifted 90˚ counter clock wise from the 0˚ base shown in Figure 3.

(4) Method

The subjects were given an explanation (in writing and through questioning) of the content of the experiment. The experiment was conducted after the subjects agreed to participate. The procedure of the experiment is shown in Figure 4. Subjects were first shown the symbol "+" in the middle of the screen to center their gaze. After three seconds the "+" symbol disappeared and a direction indicator appeared. The subjects were asked to press "enter" as soon as they recognized where north was on the indicator. After the subject responded, the indicator disappeared, then after another three seconds, a fixed point appeared. The amount of time until another stimulus appeared was randomly selected from 1, 1.5 or 2 seconds. The subjects were asked at the start of the experiment to necessarily focus on the fixed point, but when a directional indicator appeared they could let their eyes roam freely, and respond swiftly as soon as they identified which way is north. With regards to the number of directional indicators each group was shown: group (a) was shown 7; group (b), 6; group (c), 5; and group (d), 6. Each indicator was rotated as shown in Figure 3 and displayed in a random fashion. Each subject was asked to respond 96 times per experiment.

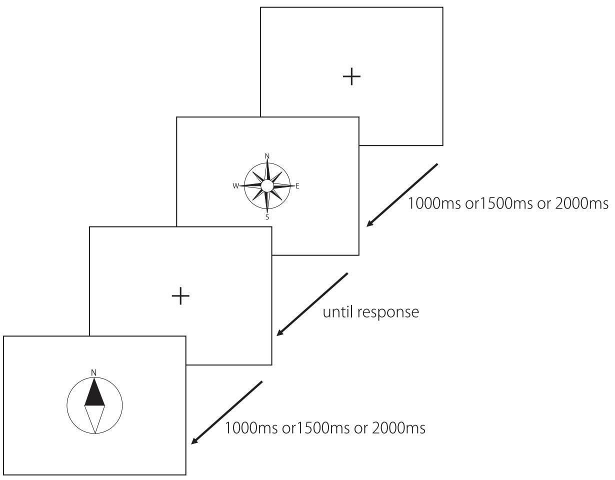

Figure 4: Cardinal direction display

2.2 Eye movement data analysis

A tracker was used to record the left eye's horizontal and vertical movements. The sampling rate for data acquisition was 0.008 second. Eye movements, fixation points and their lengths were tracked. Yamada et. al. (1986) and others' definition of the fixed point as when the angular speed of the eyes was below the 5deg/sec threshold and paused for more than 150msec was used, as seen in equation (1). The subjects' reaction time (RT) for each stimuli was measured and based on that the average value of each sample RT. was calculated.

$$\text{Angular speed} = \tan\left(\frac{\sqrt{(x_1 - X_2)^2 + (y_1 - y_2)^2}}{570}\right) / 0.008 \qquad (1)$$

x refers to amount of horizontal movement,
y to vertical movement.

3. Test results

3.1 Reaction time

Each subject's reaction time was calculated by group. Figure 5 shows the average reaction time of the 40 subjects. The reaction time for group b was 625msec, Group a was 764 msec, group c was 918 msec, group d was 1293 msec. Tukey's HSD (honest significant difference) test, a multiple comparison procedure, was performed to study the group's reaction times.

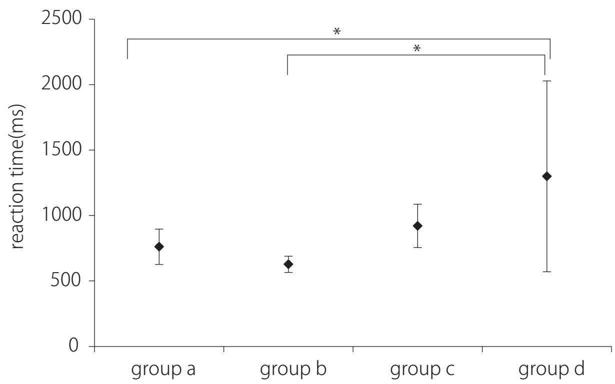

Figure 5: Average reaction time

Note: $^*p < 0.05$

A variance analysis showed that the response time differed for each group. (F (23,936) = 1.54, P < 0.01) A considerable variation was seen between groups a and d, and groups b and d, but not between the other groups. Group d showed the longest reaction time, but that could be due to the fact that the subjects in that group were shown a compass rose with 8 pointers and had to process more information before they could react.

Then compared reaction times within each group were compared. Reaction times to seven types of directional indicators in groups showed noticeable differences. (F (6,273) = 2.13, $P < 0.01$). Tukey's HSD test confirmed that a4 had a considerably longer reaction time than a6. ($p < 0.05$). Although both samples required more information to be processed, an increase of just one line in the structural element lengthened the reaction time. Furthermore, a7's reaction time was considerably longer than that of a1, a2, a4 and a5.

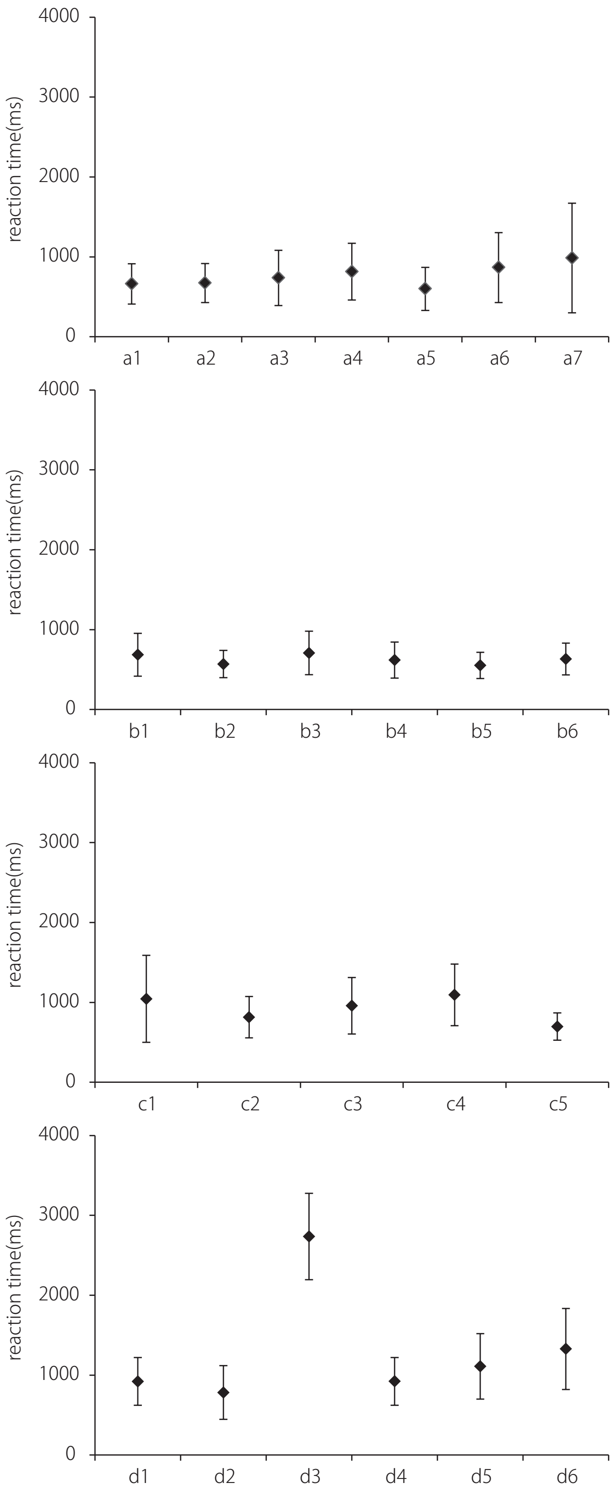

Figure 6: Average reaction time per group

A comparison between a4 and a7 confirmed an increase in extra diagonal and horizontal lines in an otherwise similar compass rose with the same amount of information, subjects spent much longer looking for the sign pointing north.

With group b, there were no discernible differences. Comparing the results of group c's five directional indicators revealed a noticeable difference (F (4,195) = 2.41, $P < 0.01$). Tukey's HSD test showed that c5's reaction time was faster than that of c3, c1 and c4 ($p < 0.05$). C5 used a marking instead of the letter "N" to denote north. But the fact that c3, c1 and c4 each had letters designating the four cardinal directions, which slowed reaction time, made c5's time appear faster. Furthermore, group d's reaction time was statistically significant (F (5,234) = 2.25, $P < 0.01$). Tukey's HSD test results showed considerably shorter reaction time in d3 against all others. The presence or absence of letter data played a big role in confirming which way was north on a compass rose. What took the longest time in identifying north in d3 was one in which the compass was completely symmetrical vertically and laterally. The absence of any letters made identifying north a little harder.

Within each group, the common factor among a5, b5, c2 and d2 directional indicators that elicited the fastest reaction time was that they all featured only one letter, the N.

The results above confirmed that the presence or absence of letter data influenced reaction times when confirming a direction on a compass rose. Also, even for samples with the same amount of letter data, structural factors made a difference in the time spent identifying which way was north.

3.2 Fixation time per cardinal directions

Measurements to find out how the eyes move, where they look and for how long when viewing a directional indicator were taken, and in order to analyze the factors that make compasses easy to read, a5, a7, b3, b5, c4, c5, d2 and d3the ones with the biggest gaps in reaction times were taken and rotated them 180˚ to disperse their points of gaze. The compass remained on screen and its onscreen duration timed until the reaction button was pressed. Each sample's display time in average was 762msec for group a, 627msec for group b, 921msec for group c, 1299msec for group d. With regards to analyzing gaze fixation times and order, the following areas a) uppermost tip of the compass rose, b) the right tip, c) the lowest tip, d) the left tip, e) the center, f) letter N, g) letter W, h) letter S, i) letter E, and j) where the lines intersect divided them up into segments were taken and an analysis of gaze fixation on each segment was conducted. Figure 7 shows the results of this analysis.

The points of gaze concentrated on the N on all the compass roses. For a5, the gaze mainly fixated on f) where N was

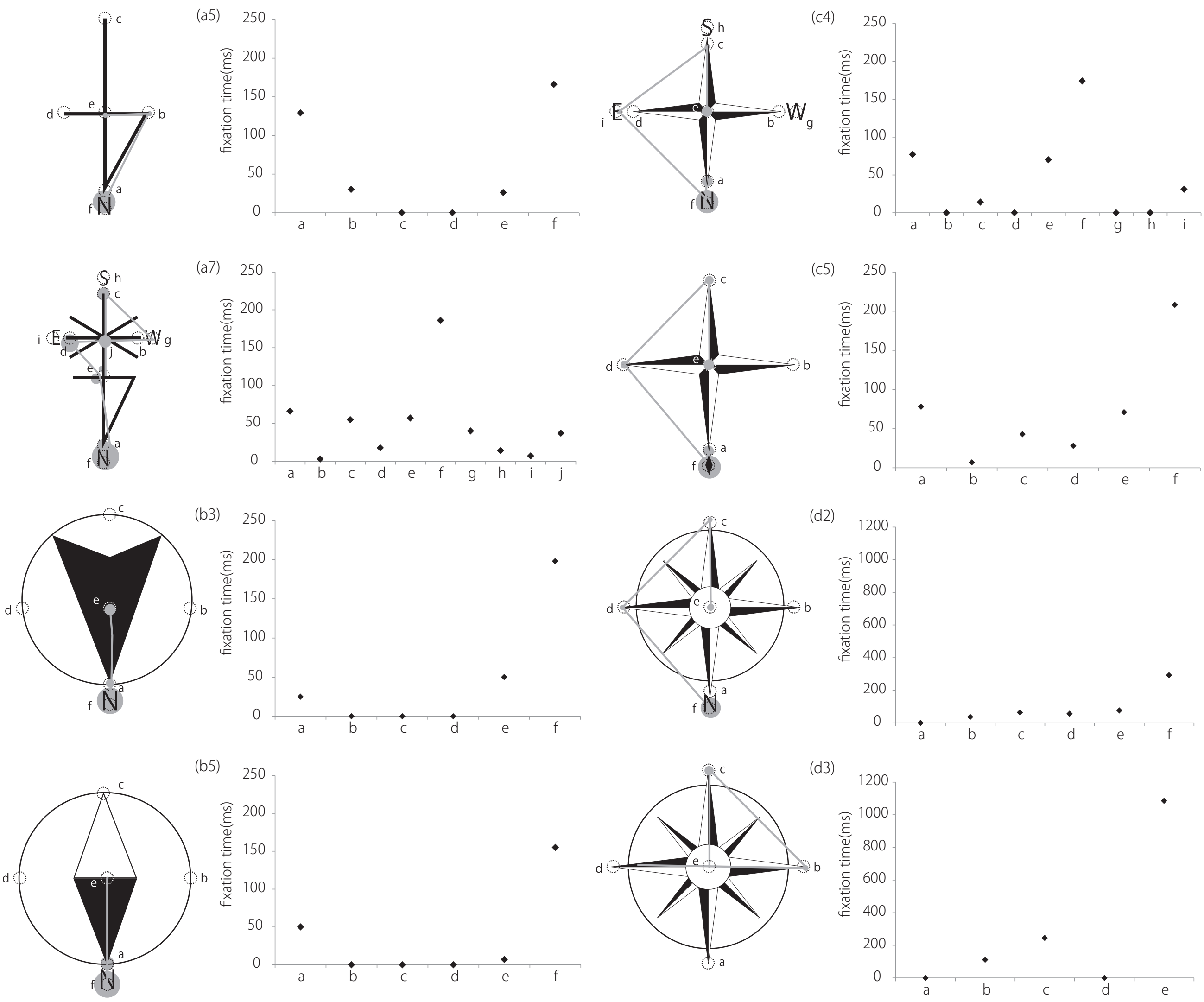

Figure 7: Fixation times and eye movements of 180-degree rotated a5, a7, b3, b5, c4, c5, d2 and d3

indicated. But in the case of a7, the gaze fixated on the j) part, where numerous lines intersected with the addition of a horizontal line. Also, with an increase in the number of letters, the point of gaze was directed in the c), d) and g) areas, widening the subjects' range of focus. When the compass rose was structured like the number 4, as in a5 and a7, the point of gaze focused on a) and f).

In b3, the point of gaze focused on e) toward the center of the compass rose, increasing the amount of time the eyes traveled toward the edge and on the letter N. Furthermore, b5 is made up of two isosceles triangles side by side, but like b3, the point of gaze focuses on f) where N is indicated. Whereas b3 draws the eyes toward the center, b5 pulls the eyes away from the center, toward the edges and the letter N. The point of gaze tended to be shorter.

With c4, the point of gaze stays for a long time on the f) area where N is, but it also goes toward e), the center, and to h), the letter S and i), the letter E. Like a7, c4 is structured with the four letters of the cardinal directions, but because of its symmetry, both vertical and lateral, the letter sections are more closely examined. On the other hand, the point of gaze is focused on f), where north would be, for c5. It is structured similarly to c4, but the difference in where the directional information is positioned on the compass alters the range of the gaze.

The point of gaze on d2, which has eight directional points, fixates for a long time on e), the central area, and concentrates on c) and d), but it is evident that the eyes also focus on f) where the N is located. Also, a major characteristic of d3 is that it does not have any letters to denote directions. For other compasses, the point of gaze focused on N or the edge, except for d3, the gaze is concentrated on e), the center of the compass rose. The point of gaze is scattered because of an absence of defining characteristics; it is vertically and laterally symmetrical and lacks letter data.

With compasses that point only in one direction, the eyes move toward N, whereas those with four or eight directional points, the increase in data forces the gaze to spread around the surrounding letters and the structural elements.

These results explains that gaze rests for a long time on the letter N when looking at a compass. The eyes put a lot of weight on N, but similar to the point of gaze distribution on abstract compass roses by Watanabe et. al., the eyes are thought to focus on the edges and boundaries of a compass. Furthermore, a directional indicator is not viewed overall but gaze is directed selectively to places that contain important information.

Especially with vertically and laterally symmetrical indicators, it was found that the gaze tended to move from the center to the upper half, to the left and then the right. This is believed to be influenced by the subjects' tendency to look at the top of the compass. However, the compass, which is perfectly symmetrical and has no letters, also draws the eyes toward the center for a long time.

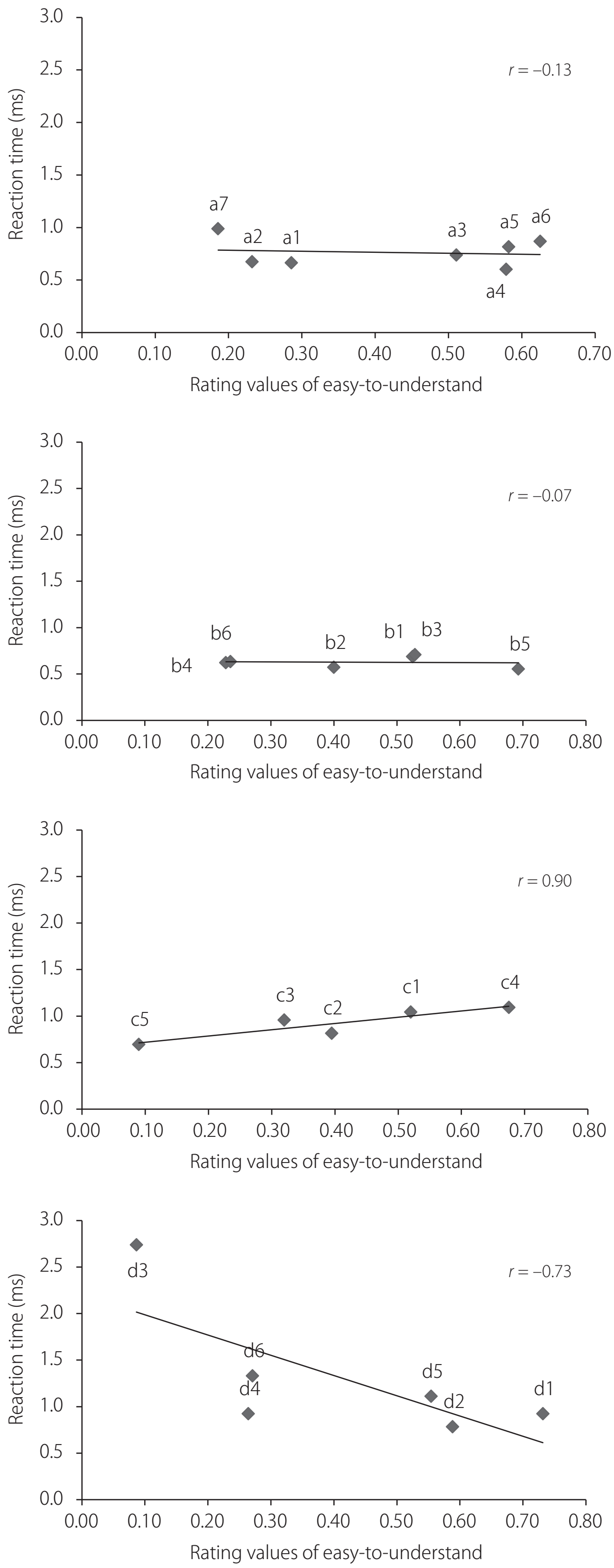

Figure 8: Reaction times and assessment scale values obtained through subjective assessments

3.5 The relationship between assessment of rating values of easy-to-understand and reaction times

In order to analyze the relationship between the intuitiveness of a compass and the time leading up to a reaction (reaction time), the coefficient of each group's reaction times was examined and the psychological scale value of an intuitive compass design obtained from the subjective analyses. Results are shown in Figure 8. The lateral axis is for the scale value, the vertical axis denotes reaction time.

For group a, it was not possible to confirm a correlation between the psychological scale value and reaction times. ($r = -0.13$, $p < 0.01$). It was not possible to confirm a correlation also in group b ($r = -0.07$, $p < 0.01$). A high negative correlation for group c ($r = 0.90$, $p < 0.01$), and a strong correlation in group d ($r = -0.73$, $p < 0.01$) was found. For all groups, with the exception of d, low correlations confirmed that paying close attention and processing information consciously as opposed to the opposite makes a difference in the reaction time to the intuitiveness of a cardinal direction.

4. Discussion

In compiling all of the above results, subjects took longer to identify north in directional indicators designed without any letters, compared with those with the letter N denoting north or a symbol indicating as such. Furthermore, the eyes moved around more and held their point of gaze longer on letter-less indicators. This indicates that directional indicators without letters are inefficient at transmitting information.

On the other hand, indicators with an N showed to elicit the shortest reaction time and fewer eye movements. This suggests that lettered direction indicators are efficient transmitters of information. These results line up closely with earlier studies (Namateme et al., 2009) involving the gaze using pictograms.

Furthermore, compass roses with 8 labeled direction points elicited a shorter reaction time than one with just an N designation. With every increase in letters and direction points, the longer the eyes took to confirm north because of all the information that needed navigation.

With the subject's attention going reflexively toward an arrow (Nakamura et al., 2002), any increase in the number of pointers means an expansion in the field that draws one's attention. Also, experiments involving a simple line-drawn direction sign reportedly showed that the gaze focuses on edges and sudden curves (Guez et al., 1994).

It has also been confirmed that the eyes, when looking for a direction on a compass, focus on the edges of the sign, where the letters are present and where the lines intersect. Additionally, signs with just the letter N as textual data create a narrower field of vision than those with all four directional points that are also labeled. It is believe that the most intuitive direction sign is in group b, ones with the fewest points of gaze and elicits the longest gaze to the letter N. In other words, the characteristics of an intuitive direction sign contains the letter N to denote north, and offers a limited travel range for the gaze, preventing the eyes from wandering. Also, fewer intersecting lines, vertical and lateral symmetry contribute to easy to understand cardinal direction signs.

5. Conclusion

This research measures where the gaze travels when looking at a directional indicator and for how long. The results in studying what constitutes an easy-to-understand sign were considered. A tracker to follow the movement of the eyes as they look at a compass rose was used, then the amount of time it took to confirm a direction and the point of gaze was analyzed.

The results can be summarized as follows:

(1) There was a tendency for the reaction time to be shorter on signs with one pointer, pointing north, instead of a sign with eight directional points. In other words, the more letters and lines there were to process, the longer it took to confirm the northerly direction.

(2) With regards to the movement of the gaze, it went initially to the center, then it stopped for a while on the letter N. The easier the compass was to understand, the less tendency there was for the eyes to wander.

(3) In an indicator with lateral and vertical symmetry, ones with fewer intersecting lines tended to be recognized as easier to read.

It is believed that the factors determining the intuitiveness of a directional indicator largely rest on whether there are letters that give directional information or if they are laterally asymmetrical. Among several theories that explain the way letters are perceived differently from graphics, there is the cerebral hemisphere process, which basically explains that the form of the stimulus processed by the left and right sides of the brain differ. The relationship between letters and graphics is material for future study.

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(Received: June 4, 2015; Accepted: June 20, 2015)