An Analysis of the Effects of Hue and Display Density on Visual Search Performance

by

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(ABSTRACT)

This study investigated the effect of hue on performance under different types of display density. In the past, researchers have primarily conceptualized density in terms of the total number of filled characters on the screen (i.e., overall density). Recently, however, Tullis (1983) suggested this definition was too restrictive. In addition to overall density, he suggested that two other types of density be considered: local density, or the number of characters immediately surrounding the target; and grouping, or the number of perceptual groups formed by the display elements. The present research explored the effect of hue using each of the types of density in three separate experiments.

Subjects were presented several profiles of job applicants on a computer screen and asked to select the applicant with the highest skill score. Density manipulations specific to each experiment were in terms of the number of profiles (Experiment 1 – overall density x hue), intra-profile spacing (Experiment 2 – local density x hue), and inter-profile spacing (Experiment 3 – grouping x hue). In all three experiments, the presence of hue was either relevant or irrelevant to the task. Results of a series of 2 x 2 x 3 ANOVAs showed that the addition of hue had a significant effect on visual search performance. The direction and magnitude of this effect depended on the relevance of hue and the specific manipulation of display density. Findings were explained in terms of the Gestalt principles of organization and several recommendations were made for screen design.

in memory of Shanta Kerkar,
a mentor and a friend

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on Visual Search Performance

Even though the cathode-ray-tube (CRT) has been in existence for nearly a century, the use of the CRT display terminal in graphics, text, and data processing has only begun to accelerate in the last twenty years. The key to the attractiveness of the CRT terminal has been the rapid processing speed and large volumes of data that can be handled. Increased usage of the computer has led to a greater emphasis in the human/computer interface. Galitz (1980) stated that the effectiveness of human interaction with computers depends on how easy the system is to operate. One way of reducing a system's complexity involves the formatting of display items. Formatting display items removes the burden of scanning through large amounts of information by eliminating irrelevant items and presenting relevant items in a more structured sequence. Cakir, Hart, and Stewart (1980) suggested that formatting (i.e., how information is coded) was the most important feature in minimizing a system's complexity. They stated that the operator is concerned with basically two format codes: alphanumeric codes and enhancement codes. Alphanumeric codes involve the display of information in some abbreviated form. For example, airline destinations such as Roanoke Regional Airport would appear as ROA on a visual display. Postal zip codes and telephone area codes are other examples of how information can be transformed into an abbreviated display format. On the other hand, enhancement codes are used to delineate a selected part of a display screen. For example, blink coding or hue might be used to highlight certain characters or locations on a display.

Tullis (1981) illustrated the effectiveness of formatting in a study using employees at Bell Telephone Company. He compared a narrative written format to a structured schematic format, and found a 3.3 second decrease per screen in the time necessary to retrieve information when going from the narrative to the schematic format. Even though this gain appears modest, its importance is recognized when viewed in terms of how often these screens are used on the job. Tullis estimated that this particular section of Bell Telephone viewed over 344 million screens per year. Therefore, the 3.3 second decrease in search time translated into an overall savings of approximately 79-person years.

Studies such as Tullis (1981) illustrate the importance of formatting codes in the decrease of visual search time. The purpose of this paper is to explore the effectiveness of hue highlighting (an enhancement code) and display density on visual search performance. Several studies have looked at the effects of hue highlighting and display density separately, but very few have looked at their combined effects. For example, Christ (1975) reviewed 42 studies that used hue as an independent variable and concluded that the effectiveness of hue coding was highly task specific. However, he did not report the levels of display density in any of those studies that he reviewed. In contrast, those studies manipulating both hue and display density have shown increases in performance across several different tasks (e.g. Alden, Wedell, & Kanarick, 1979; Kopala, 1979). However, the studies that have dealt with the combination of hue and density have limited themselves to one definition of display density. Display density has been typically defined as the total number of characters displayed or what is more commonly known as overall density. More recently, Tullis (1983) has argued that overall density is but one of the three ways density can be defined. Density can be further defined in terms of local density (the number of filled character spaces near each target character) and grouping (the extent to which items form well-defined perceptual groups.) Each of these definitions represents application of the Gestalt organizational principles of proximity and contrast (Wertheimer, 1923/1958). The contrast between a target stimulus and its background achieved by the addition of hue should vary with the proximal arrangement of the background stimuli (i.e., definition of display density). Therefore, this paper addressed the combination of hue and each definition of display density in three separate experiments. Specifically, each experiment used a factorial combination of hue with either overall, local, or group density.

Before addressing the actual experiments, a review of the literature relevant to each of the variables – hue, overall density, local density, and grouping – will be presented in separate sections. Specific issues in each section will be discussed in terms of (1) general guidelines, (2) empirical data, and (3) an integration of those findings.

Hue

General Guidelines. Color is defined in terms of three components – hue, brightness, and saturation; however, most guidelines for using color in display design restrict themselves to only include manipulations of hue. Studies concerning the effectiveness of color as an enhancement code

have held both brightness and saturation constant. Therefore, what several authors have referred to as color is referenced as hue in this paper.

The addition of different hues to the CRT has added a new dimension to the processing of information. According to Cakir et al. (1980), hue can be used to: (a) aid in locating a particular symbol, word, or item in a cluttered display, (b) alert the user to a changed status in the system, (c) separate information categories, and (d) provide greater contrast between display components. In essence, Cakir and his colleagues have reiterated the Gestalt organizational principle of contrast. Wertheimer (1923/1958) suggested that variations in hue permit a differentiation between an object and its background; therefore, attention can be focused on the enhanced item. A few studies, however, point out that this differentiation might be detrimental to performance if the enhanced item is irrelevant to the task being performed (Krebs, 1978).

The foremost example of how hue can be detrimental to performance is the Stroop Interference Effect (Stroop, 1935). In the original experiment, subjects were asked to name the ink color in which a word was printed, while ignoring the word itself. When the incidental features of the stimulus (the word's meaning) were incongruent with the critical feature (the word's printed ink color), interference occurred. That is, when the word "green" appeared in red, subjects' responses were inhibited. This effect has been replicated using different modalities and in several applied settings (e.g., Simon, 1969; Whitaker, 1985). It was first thought that the Stroop Interference Effect was due to the perceptual inhibition caused by the incidental feature. That is, the presence of an irrelevant hue inhibited the subject from encoding the correct information. More recently, however, it has been shown that this effect is not due to perceptual inhibition, but rather response competition between the incidental and target colors' verbal labels.

Despite potential decrements to performance, many office automation guidelines (e.g., Cakir et al., 1980; Galitz, 1980) still encourage the use of hue coding to enhance display formats. Most suggest that red is the most discriminable of all hues on a CRT monitor (Cakir et al., 1980; Krebs, 1978; Reynolds, White, & Hilgendorf, 1972). The use of a red hue is not only beneficial to performance, it also seems to be preferred by users. Subjects have shown a preference for red when viewing CRTs, reporting it was "stimulating" and "easy to read" (Beach, 1973). In an attempt to explain these subjective preferences, Tedford, Berquist, and Flynn (1977) found that numbers of

identical height appeared to be larger when presented in red as opposed to being presented in blue. They concluded that so-called "warm hues" (red, yellow) appear larger than "cool hues" (green, blue). This finding is consistent with previous work done on the illusory effects of warm colors (Bevan & Dukes, 1953; Grundlach & Machoubrey, 1931; Wallis, 1935).

Empirical data. Even though the majority of computer and office automation guidelines recommend the use of hue highlighting, empirical evidence on the effectiveness of hue is equivocal. Christ (1975) reviewed all the literature between 1952 and 1973 that addressed the effect of hue coding on identification accuracy and search time in aircraft flight simulation tasks. Within each task a distinction was made between the use of hue as a nonredundant or redundant target attribute. Target attributes were considered to be nonredundant if the target could only be located in terms of a single attribute, say their hue. Target attributes were considered redundant if they were perfectly correlated. That is, the target could be located in terms of either attribute, say their hue or their shape. When hue was a nonredundant target attribute, Christ reported decreases in both error rate and search time of up to 200% as compared to a monochromatic screen. However, evidence related to the use of hue as a redundant target attribute was mixed. There were gains in identification accuracy of 60% when hue was redundant with size; 104% with brightness; and 61% for size and brightness combinations (hue was partially redundant with size and partially with brightness). However, in tasks measuring search time, the addition of hue as a redundant attribute did not facilitate performance and at times even lead to a decrement. While the studies reported by Christ used flight simulation tasks, studies using other tasks have reached similar conclusions.

Luria and Strauss (1975) had subjects search for a target dial in a 4 x 4 array of dials differentiated by either hue, shape, or a combination of the two (where hue was redundant with shape). Search times for nonredundant hue coded dials were the shortest, followed by the combination of hue and shape, and nonredundant shape coded dials. All three groups, however, surpassed the control group in which the dials were all the same. Bartram (1980) compared the efficacy of nonredundant and redundant hue codes in a task measuring the ease of comprehension of bus-route information. Subjects were required to find the proper route between designated locations and both their response times and error rates were measured. He found that schematic

road maps using a nonredundant hue code proved to be the most effective means of displaying information.

Wedell and Alden (1973) also found that redundant hue coding was inferior to several nonredundant coding strategies in a variety of search tasks performed by air-traffic controllers. Subjects were required to search a CRT for different types of aircraft at various altitudes and then identify both the number and the location of each type. Several different hues were used and each was redundant with a specific type of aircraft. Even though the presence of a redundant hue did not significantly decrease search time, it was helpful in retaining the number of aircraft at specific altitudes. Subjects said they were able to group or categorize aircraft on the basis of hue information, thus adding a third dimension to a two-dimensional display. In a subsequent study, Alden et al. (1979) showed that redundant hue coding was inferior to both nonredundant symbol- and nonredundant hue-coding. Subjects were required to locate and identify aircraft on several target dials, and most of them stated they ignored the redundant code and used it primarily to separate adjacent dials.

In conclusion, the use of hue as a nonredundant target attribute has shown decreases in both error rate and search time across several tasks. The magnitude of the decrease, however, is highly dependent on the level of task difficulty (Christ, 1977). The usefulness of hue as a redundant target attribute is equivocal. While reporting overwhelming gains in identification accuracy, performance decrements have been shown in tasks measuring search time. The only redeeming quality of redundant hue coding in tasks measuring search time is that it appears to (1) aid in the organization of items (Kopala, 1979; Shontz, Trumm, & Williams, 1971) and (2) help subjects categorize information (Alden et al., 1979; Wedell & Alden, 1973)

Integration. Christ (1975) suggested that the equivocal nature of the data regarding hue as a redundant code might be the result of several factors. First, in most of the studies, highly complex tasks such as air-traffic simulation were performed by inexperienced subjects. Second, in all the studies reported, subjects devoted their full attention to a single task. In real world situations, the operator is typically trained on the job, and therefore, possesses a level of experience that the laboratory subject might not have. Furthermore, the displays are often more complex, and require

the operator to process information simultaneously from several studies. In this light, hue may only be helpful in such complex work environments.

To deal with these issues, Christ (1977) had practiced subjects perform multiple tasks. He found that the effectiveness of hue coding relative to shape-, digit-, and letter-coding was equivocal. The direction and magnitude of the effect of hue varied as a function of task variables. Christ and Corso (1983) conducted several studies to evaluate the effectiveness of several coding techniques (letter-, digit-, shape-, and hue-coding). Subjects saw both single and dual code displays in three isolated tasks (choice reaction, search and locate, or identification-memory) and multiple tasks combining the three. They found that the relative effectiveness of different visual codes, especially hue, varied as a function of practice, the type of task, and the response measured.

Display Density as an Additional Variable

Another variable that affects the relationship between hue and performance is the density of characters on the display. Christ (1975) did not define the number or the arrangement of characters used in those studies he reported. In fact, he even suggested that display density might have confounded the effect hue had on speed and accuracy, but did not test this hypothesis. More recently, studies have shown that the effectiveness of hue coding increases as displays become more cluttered or complex (e.g., Alden et al., 1979; Kopala, 1979), thus confirming Christ's earlier hypothesis.

Although Christ's primary interest was the effectiveness of hue in aircraft simulation tasks, several studies have shown an interaction between hue and display density on a number of other tasks. A series of studies by Carter and his colleagues (Cahill & Carter 1976; Carter, 1979; Carter, 1982; and Carter & Cahill, 1979), manipulated both display density and the number of hues used in several different tasks. In these studies, display density was defined in terms of the total number of elements on the screen. When hue was used as an enhancement code, they reported an interaction between hue and display density; that is, search time was minimized when hue was used with a low density screen. Carter (1979) reported that doubling the display density from 30 to 60 items resulted in a 108% increase in search times for monochromatic displays, but only 17% for hue coded displays. Luder (1984) and Noble and Sanders (1980) also reported that as display

density increased, error rate and response time on monochromatic screens increased at a greater rate than for hue screens.

In conclusion, several studies have shown strong evidence for the effectiveness of hue when the level of display density was identified. However, those studies restricted their definition of display density to the total number of characters displayed or the number of noise elements. More recently, Tullis (1983) has suggested that display density can be defined in the following three ways: (1) overall density – the total number of characters displayed; (2) local density – the number of filled character spaces near each target character; and (3) grouping – the extent to which items form well-defined perceptual groups.

When density is not conceptualized merely in terms of overall density, the effects of hue and display density on performance can be more precisely studied. The following sections will review the literature on each of the three definitions of display density suggested by Tullis (1983), and how they affect identification accuracy and search time.

Overall Density

General Guidelines. Overall density has been defined as the number of characters displayed, often expressed as a percentage of the total character spaces available (Carter, 1979; Carter, 1982; Carter & Cahill, 1979; Tullis, 1983). In general, increases in overall density cause perceptual overload and lead to a decrement in performance (Green, 1976). Galitz (1980) recommended that the display should not appear cluttered so as to avoid confusion. Such confusion could in turn lead to an increase in both search time and error rate (Engel & Granda, 1975). Moreover, cluttered display screens can lead to psychological stress (Green, 1976).

Empirical data. Several studies have shown that both search time and error rate increase as a function of overall density both in simple visual search and identification tasks (Atkinson, Holmgren, & Juola, 1969; Estes & Taylor, 1966; Ringel & Hammer, 1964) and in more complex decision-making tasks (Burns, 1979; Egeth, Atkinson, Gilmore, & Marcus, 1973; Teichner & Mocharnuk, 1979). Several studies have been conducted to generate specific guidelines for overall density in visual displays. Dodson and Shields (1978) had subjects perform a visual search task in which different levels of overall density (30%, 50%, and 70%) were used. It was found that search time increased as a function of overall density. Moreover, this increase was exponential when

overall density exceeded 60%. Based on these findings, Dodson and Shields concluded that an upper boundary be set on overall density at 60% of the total character spaces available. A set of studies conducted at the Marshall Space Flight Center (NASA, 1980) also concluded that both accuracy and response time began to degrade rapidly when overall density exceeded 60%.

Smith (1980, 1981, 1982) did not refer to an upper limit on display density, but instead classified it in terms of low and high levels of overall density (1982, p. 53). He stated that high density was anything exceeding 600 characters and that low density was anything below 300 characters. Translated to a standard 24 x 80 character CRT, the corresponding percentages were 31.2% for high density and 15.6% for low. Danchak (1976) also concluded that the optimal level of overall density be approximately 15% of the display screen, with the rest being left as white space.

Integration. Tullis (1983) attempted to synthesize the recommendations for overall density by collecting a random sample of information screens used by employees at Bell Telephone. This sample had a mean overall density of 14.2% with a standard deviation of 7.1% and a range from 0.9% to 27.9%. Tullis concluded that his mean value of 14.2% was similar to Danchak's optimal density level of 15% and Smith's low density level of 15.6%. He further cited that none of the sampled screens exceeded Smith's high density level of 31.2%.

While Tullis' conclusions were based on a very small sample, there is substantial evidence that 60% overall density is the level of visual overload. Empirical evidence suggests that both search time and error rate increase linearly with overall density until it reaches 60%. At that point, search time is said to increase exponentially (Dodson & Shields, 1978; NASA, 1980). Figure 1 depicts graphically the relationship between performance and overall density (NASA, 1980).

Insert Figure 1 about here.

Local Density

General Guidelines. The concept of local density is closely related to overall density. As the number of total characters per screen increase, the individual characters would naturally be more tightly packed. However, when working within the guideline of 31.2% overall density suggested

by Smith (1982), local density could vary significantly without affecting overall density. This point can be best illustrated in a figure used by Tullis (1983). Both displays in Figure 2 have the same number of characters (overall density), but in one case all the characters are packed into one corner of the display (high local density) and in the other they are uniformly separated (low local density).

Insert Figure 2 about here.

Several authors have suggested specific guidelines concerning local density. Each of these guidelines are based on the Gestalt principle of proximity – items that appear closer together tend to be grouped together (Wertheimer, 1923/1958). Therefore, increasing the distance between items can reduce the confusion between a target and its background.

Jones (1978) stated that "spacing makes it easier to find ones way around by breaking up text into logical segments" (p. 156). He recommended that spacing should take the form of white horizontal bars (line feeds) or white vertical bars (tabulation). Galitz (1978, 1980) concluded that in order to avoid confusion, screen elements should be broken up with blank spaces. Furthermore, vertical spacing should be done by inserting at least one space between columns of related information. When spacing items horizontally, Galitz (1980) advised at least five spaces between the last character in the longest data entry in one column and the first character in the adjacent column.

To ensure adequate discrimination between individual characters, Cakir et al. (1980) recommended that intercharacter spacing should not be less than 20% or greater than 50% of character width. They further suggested that interline spacing should not be less than 100% and not greater than 150% of the character height; however, no rationale was given for their recommendations.

Empirical data. Despite an increasing number of guidelines, there have been few studies in which local density has been manipulated. These have involved the manipulation of local density in terms of: (a) interline spacing, and (b) inter-character spacing. The results of such studies are mixed. Ringel and Hammer (1964) showed subjects tabular displays in which the ratio of letter height to the interline spacing was 1:4 (low local density) and 1:2 (high local density). They found

that search time for high density was shorter than the low density condition. Therefore, it appears that high local density enhances performance. In contrast, Kolers, Duchnicky, and Ferguson (1981) found a degradation of performance when going from low (double-spacing of text) to high (single-spacing) density. Kruk and Muter (1984) verified these results. Therefore, the effect of interline spacing on performance is not clear-cut.

Brown and Monk (1975) manipulated local density by varying the number of characters in positions immediately adjacent to the target character. More specifically, they varied the number of background dots in a 3 x 3 matrix of character spaces centered around a double dot target. Search time was found to increase as a function of the number of background dots. The authors concluded that congested target areas camouflaged the target, and produced an increase in search time (e.g., Monk & Brown, 1975). Egeth et al. (1973) manipulated local density by using a linear or circular array of 1 to 5 characters. The separation between characters was 0.009 rad in the linear array and 0.024 rad in the circular array. Search times increased when a linear array was used, suggesting that higher local density caused a degradation in performance. Egeth et al. referred to the interference between a target and its background as the most critical element in decreasing reaction time and response accuracy. Thus, they advocated spacing elements far enough apart to avoid the perceptual integration of different characters. Several studies have, however, cited evidence to the contrary.

Swanston and Walley (1984) had subjects read tabulated information (columnar data from phone directories) following a change in locus of fixation. Subjects fixated on a marked point on a CRT and then looked across to an entry in a table of 3-digit numbers. They found that reaction time increased as local density of the table decreased. Treisman (1982) also found that the time needed to find a target character was significantly longer with less dense displays.

Integration. Results of both interline and inter-character manipulations of local density are mixed. Interline spacing degrades performance in some situations (Ringel & Hammer, 1964) and actually improves performance in others (Brown & Monk, 1975). To reconcile this contradiction, Tullis (1983) measured the ratio of character height to interline spacing and found that Kolers et al. (1981) single spacing manipulation yielded a ratio of 1:0.3and their double-spacing manipulation a ratio of about 1:1.7. This ratio of 1:1.7 approximates Ringel and Hammer's (1964) 1:2 and is

relatively close to Cakir et al.'s (1980) 1:1.5. Based on these findings, Tullis concluded that the relationship between search time and local density approached a U-shaped function with the optimal height-interline ratio being approximately 1:2.

Like the results of research on interline spacing, the findings in inter-character manipulations of local density are equivocal. A re-evaluation of the literature by Tullis (1983) found that Triesman's character separations ranged from 0.037 rad to 0.075 rad. Therefore, Treisman's study was concerned with much lower local density levels than studies reported by Brown and Monk (1975) and Egeth et al. (1973). Re-evaluation of Swanston and Walley (1984) showed that their character separations were even higher than Triesman's upper boundary of 0.075 rad, thus resulting in even lower levels of local density. These findings are consistent with Tullis' (1983) speculation that the relationship between search time and local density is a U-shaped function. Items that occur within a single fixation of attention are combined to form one object. Thus, if attention is overloaded by high levels of local density, items may be wrongly recombined forming what Treisman and Schmidt (1982) referred to as illusory conjunctions. At the other extreme, large separations of items (low local density) increase the number of eye-movements necessary to encode information causing an increase in search times (Collins & Eriksen, 1967).

Suppose the relationship between performance (search time and error rate) and local density is a U-shaped function, then the major concern is finding the optimum level of local density. Several studies have suggested that the answer to this question lies in terms of some characteristic of the human visual system. Fine visual discrimination takes place in the central foveal area of the retina. Woodrow (1938) found that when subjects fixated on a point, they saw information within a 5 deg solid cone to 50% accuracy. Cakir et al. (1980) recommended that the optimal CRT-viewing distance was between 450 and 500mm. Therefore using a mean of 475mm, the 5 deg angle subtended off the fovea translates into a circle with a 41.8mm diameter on the face of the CRT. Based on the average distance between character centers of 2.8mm horizontal and 5.6mm vertical (Tullis, 1983), the 5 deg visual angle includes approximately 88 spaces centered around the point of fixation. Figure 3 illustrates this visual parameter.

Insert Figure 3 about here.

Therefore, local density could be measured by averaging the percentage of characters in those 88 spaces surrounding each character on the screen. Tullis (1983) stated that such an index would fail to account for different sensitivities of the eye within the 5 deg subtended visual angle. Thus, a more realistic index of local density would involve weighting those characters closer to the center more heavily than those farther out.

Insert Figure 4 about here.

Figure 4 is a representation of the weighting scheme proposed by Tullis (1983). He assigned the center fixation character a value of 10 and those characters outside the circle a value of 0. Using a linear weighing system, the weight assigned to each character space is inversely proportional to its distance from the fixation point (see Figure 2). For example, given the "O" is the target stimulus, the left display in Figure 2 would have an overall density of 50% and a local density of 72%. The right display would also have an overall density of 50%, but by uniformly spacing the characters, local density becomes 39%.

In conclusion, the relationship between local density and search time/error rate approximate a U-shaped function; whether local density is measured in terms of interline or inter-character spacing. Figure 5 graphically depicts the relationship between local density and performance. Furthermore, Tullis (1983) has suggested a technique for measuring local density based on the 5 deg visual acuity angle subtended on the fovea.

Insert Figure 5 about here.

Grouping

General Guidelines. Garner (1970) defined a group as an arrangement of characters in "good form". The concept of good form is very similar to the concept of local density. Jones (1978) stated

that spacing (increasing local density) allows information to be broken into logical sets or groups. Grouping relevant information has been shown to minimize search time. Cakir et al. (1980) stated that grouping improves readability and can highlight the relationships between different groups of data. Grouping and the use of blank spaces can also provide structure in the display and to aid in both recognition and identification of specific items. Cropper and Evans (1968) recommended that presenting information in chunks overcomes perceptual overloading in high density displays.

Galitz (1978, 1980) and Bailey (1982) both suggested the use of grouping when displaying information. Bailey suggested that groups of items be separated by 3 to 5 rows or columns of blank spaces. He justified such a procedure by stating that it enhanced the structure of the display and helped to organize information. To attract the viewer's attention, Green (1976) concluded that formats must be simple, balanced, and have well defined margins. All three of these criteria can be met by grouping relevant information.

Because of the similarity between grouping and local density, Woodrow's (1938) finding concerning visual acuity may shed some light on the parameters of the optimal group. Cropper and Evans (1968) and Danchak (1976) stated that this 5 deg visual angle subtended on the fovea best defined the critical area of the display screen and that information should be formatted accordingly. That is, each group of symbols containing task-relevant information should be displayed within the 88 character circle subtended on the display screen. Danchak further recommended that each of these so called "critical areas" only contain one bit of task relevant information (p. 34).

Empirical data. A few studies have attempted to manipulate Danchak's recommendation for spatial grouping. Woodward (1972) found that the time needed to compare pairs of 3-digit numbers was shorter when the numbers were presented horizontally than when they were presented vertically. He explained this finding by showing that in the horizontal arrangement both numbers fell within the 5 deg visual angle while in the vertical arrangement only one of the numbers fell in the 5 deg visual angle. What he failed to mention was that his results could have been due to the habitual reading direction of his English speaking subject pool. Within a Chinese culture, one that reads vertically, the results may be just the opposite.

Perhaps the most extensive study on the effects of grouping was done by A. Triesman (1982). She displayed 36 characters in either 1, 4, 9, 18, or 36 groups with each group composed of homogeneous letters except for the group containing the target. She found that the time to detect a target letter defined by a conjunction of features (i.e., a green X among green H's and red X's) increased as a function of the number of groups, even when overall and local density were held constant. On the other hand, the number of groups had little effect on the time necessary to detect a target letter defined by disjunctive features (i.e., a blue H among red H's and green X's). Triesman concluded that when homogenous groups of items are presented in a display, *groups* rather than *individual* items will be serially scanned. Attention is therefore allocated in a hierarchical fashion, first to the group as a whole and only subsequently to the elements of a group (e.g., Kahneman & Henik, 1977). This explains why an increase in the number of groups increased search time in the conjunctive condition whereas no such increase was evident in the disjunctive condition.

Integration. Despite the evidence that grouping of relevant information seems to facilitate performance, little has been done to set parameters on grouping. Garner (1970) stated that a group was a collection of symbols in "good form", but little has been done to quantify "good form". The question of what defines a group, however, is not a new one. Gestalt psychologists were the first to study the effects of grouping. Wertheimer (1923/1958) stated that grouping occurred on the basis of small distances or what is more commonly titled the organizational principle of proximity. Zahn (1971) applied the Gestalt principle of proximity to a computer-based group detection technique. Zahn's technique involved two steps. First, the differences between each character and its nearest neighbor are computed. Second, a graph is formed by connecting any pair of characters separated by less than the mean value. A group is therefore defined as any interconnecting set of characters. Figure 6 is an illustration of the method described by Zahn (1971).

Insert Figure 6 about here.

Other parameters that need to be considered are (1) the optimal number of groups and (2) the optimal number of characters per group. Triesman (1982) stated that the fewer the groups the better, and that performance decreases linearly with the number of groups. However, due to the

perceptual limitations of a single eye fixation and the physical limitations of the screen, there is a ceiling on the number of groups that can appear on the screen at one time. After that number is exceeded, both search time and error rate would increase exponentially.

Insert Figure 7 about here.

Figure 7 illustrates the recommendation for the maximum number of groups on a standard CRT screen. Tullis' (1983) procedure for measuring local density is a circle inscribed within a rectangle 15 units horizontal and 7 units vertical. Using a standard 24 x 80 character CRT and Galitz's (1978, 1980) spacing recommendation of 5 spaces horizontal and 1 space vertical between pieces of information, the optimal number of groups is 12. It should be noted that groups smaller than 88 characters should not overlap the critical area of 15 x 7 units for it would cause the user to combine the two chunks of information forming an illusory conjunction (Triesman & Schmidt, 1982; Danchak, 1976, p.34).

Insert Figure 8 about here.

The number of characters per group must also be considered. The maximum character spaces in a perceptual group is 88 (see Figure 4), therefore both search time and error rate would increase exponentially when the 88 character limitation is exceeded. However, 12 groups with 88 characters translates into an overall density of 1056 characters or 55% of a 24 x 80 CRT. This far exceeds Smith's (1982) upper boundary of optimal or even workable overall density. Smith concluded that density should not exceed 31.2% or 600 characters. Using the 12 group upper boundary on a standard CRT, each group should therefore not exceed 50 characters. Therefore, the relationship between performance measures and grouping varies as a function of two variables: (a) the total number of groups; and (b) the total number of characters per group. Figure 8 depicts the relationship between grouping and both search time and error rate based on these two functions. The function increases linearly until some overload point (12,50), at which the function becomes

exponential. These are, however, speculations based on previously cited parameters and have not been subject to empirical verification.

Overview of the Experiments

As discussed in the last three sections, display density can be described in terms of three distinct definitions rather than just one global definition. Although overall density, local density, and grouping are not independent of one another, each of these definitions of density exhibits a unique relationship with both search time and error rate. Search time and error rate increase linearly with overall density until it reaches a level beyond which the function becomes exponential. The relationship between local density and these two performance measures is a U-shaped function, while grouping is a function of two variables: the number of groups, and the number of characters per group. Both search time and error rate increase linearly with these two components of grouping until reaching a threshold point at which time the function becomes exponential.

Studies have shown that performance varies when certain portions of a screen are enhanced with a specific hue. In general, the effectiveness of hue as an enhancement code is highly task specific – varying as a function of practice, the type of task, and the response measured (Christ, 1975, 1977). However, several studies have shown that as display density increases, performance degrades at a much faster rate for monochromatic displays as opposed to displays using hue as an enhancer.

At present, research studying the combined effects of hue and display density has defined display density in terms of the total number of items on a single screen or what Tullis (1983) referred to as overall density. However, this definition is too restrictive, and does not incorporate such factors as local density – the density of items immediately surrounding the target item, and grouping – the separation of items into logical sets. Each of these additional definitions exhibits a unique relationship to performance; therefore, the findings of studies combining hue and overall density cannot be generalized to these other definitions. The present study first examined the combined effects of hue and overall density on visual search performance, and then addressed the combination of hue with each of the two additional definitions suggested by Tullis (1983).

In three separate experiments, the presence or absence of hue was factorially combined with high and low levels of display density. In Experiment 1 – presence of hue vs. no hue was

orthogonally combined with high and low overall density; Experiment 2 – presence of hue vs. no hue was orthogonally combined with high and low local density; and Experiment 3 – presence of hue vs. no hue was orthogonally combined with grouped and ungrouped density. Each of the three experiments consisted of two parts, depending on whether the presence of hue was relevant (part a) or irrelevant (part b) to the task. Each experiment (1a, 1b, 2a...) was run separately using different subjects. However, the task was the same – subjects were required to view several job applicant profiles on a computer screen and select the applicant with the highest skill score. In the relevant hue condition, the target dimension was highlighted in red; in the irrelevant hue condition, one dimension was randomly highlighted from trial to trial. In the control condition, where hue was absent, all information was presented in white on black. Within each part, performance was measured in terms of search time and number of errors. The design was the same for both, involving two levels of hue (no hue vs. hue) manipulated as a within-subjects variable, and two levels of display density (high vs. low) manipulated as a between-subjects variable. Furthermore, the trials were broken into three blocks (trials 1-20, 21-40, 41-60) so that learning effects could be analyzed.

Experimental Hypotheses.

In Experiment 1, search time and number of errors should vary as a function of the relevance and presence of hue, and the level of overall density. When hue is relevant to the task, the addition of hue should lead to greater decreases in search time and number of errors for high overall density as opposed to low overall density. This is consistent with the previous research on hue and overall density (Carter, 1979, 1982). This difference should become even more apparent as the subject learns the task (Christ & Corso, 1983).

When hue is irrelevant to the task, the addition of hue should cause interference between the hue coded dimension and the target dimension. That is, search time and the number of errors should increase relative to the control (no hue) condition. Furthermore, this increase should be greater for the high overall density condition as opposed to the low overall density condition. As in the relevant phase, this increase should decrease as a function of practice.

In Experiment 2, search time and the number of errors should vary as a function of the relevance and presence of hue, and the level of local density. According to Wertheimer (1923/1958),

the greatest contrast occurs in a homogeneous field. Local density has been defined in terms of the number of characters within the 88 character circle subtended onto the face of the screen. Therefore, the density condition maximizing the homogeneity of the 88 character circle (total field) will maximize the effectiveness of hue as an enhancement code. That is, the addition of hue should lead to greater decreases in search time and number of errors for levels of high local density as opposed to low local density.

In the irrelevant hue condition, the interference between the hue coded dimension and the target dimension should be present for both levels of local density. However, because of the greater contrast, the effect should be greater in the high local density condition. The interaction between hue and local density for both the relevant- and irrelevant-hue conditions should show the same learning curves as in Experiment 1. That is, the magnitude of the effect for both phases (relevant and irrelevant) should decrease significantly from block 1 to block 3.

In Experiment 3, the homogeneity (local density) of the total field was equal for both the grouped and ungrouped conditions. However, within the larger field – the entire screen – the ungrouped condition represents a more homogeneous field (equal proximity of symbols), thus allowing for a greater contrast. Although the addition of relevant hue should decrease search time and number of errors for both conditions, there should be a greater decrease when going from no hue to the addition of a relevant hue in the ungrouped condition as opposed to the grouped condition. Likewise, there should be a greater increase in both search time and number of errors when going from no hue to the presence of of an irrelevant hue in the ungrouped condition as opposed to the grouped condition. The magnitude of this effect should also dissipate from block 1 to block 3.

In summary, there should be an interaction between the presence of hue and each definition of display density. Search time and number of errors should be lower when going from no hue to relevant hue in conditions of high overall density (Experiment 1a), high local density (Experiment 2a), and when the alphanumeric symbols are ungrouped (Experiment 3a). The same interaction should occur when hue is relevant, with the exception that search time and error rate should increase.

Experiment 1

Method

Subjects and Design. Sixty undergraduate students at Virginia Tech participated in the study for extra credit. Each subject was tested individually in a session that lasted approximately thirty minutes. The experiment itself was divided into two parts: Experiment 1a – where the presence of hue was relevant to the task, and Experiment 1b – where the presence of hue was irrelevant to the task. The two experiments used the same procedure, but with different subjects. Therefore, thirty students participated in Experiment 1a and thirty different students participated in Experiment 1b. Within each experiment, subjects were randomly assigned to one of two density conditions (low or high overall density). Each subject then completed a visual search task twice: sixty trials with the red hue and sixty trials without the red hue. The order in which the subjects completed the task (hue – no hue, or no hue – hue)was counterbalanced across subjects.

In each experiment, subjects reviewed job applicants on four different dimensions – skill, motivation, IQ, and experience. Each dimension had a corresponding score ranging from 1 to 50 with a mean of 25 and a standard deviation of 2.5. Subjects had to selectively attend to one target dimension (skill) and then choose the applicant with the highest skill score. In the hue condition, one of the dimensions and its corresponding numerical value was highlighted in red, while the other dimensions appeared in white against a black background. In the no hue condition, all the information on the screen appeared in white against a black background. The particular dimension that was highlighted depended on whether hue was relevant or irrelevant to the task. In Experiment 1a, hue was relevant to the task. Therefore, in the relevant hue condition, skill was always the highlighted dimension. When hue was irrelevant to the task (Experiment 1b), one of the four dimension was randomly highlighted from trial to trial. The target dimension was included in the random highlighting scheme so that subjects could not automatically discard the hue coded dimension in their search for the applicant with the highest skill level.

The computer's dial setting for the intensity and saturation of both foreground hues was kept constant for all subjects. Local density and grouping were also held constant for all subjects. So that subjects attended to the skill dimension and not to a particular location on the CRT, the presentation order of the cues varied from trial to trial. Therefore, local density also varied

depending on whether "skill" was the first, second, third, or fourth dimension listed. The calculated mean local density for both density conditions was 30.93% with a standard deviation of 2.61% and a range from 27.77% (skill in the fourth position) to 34.17% (skill in the second position). Grouping was also held constant in both conditions. While the number of groups differed, the number of characters per group and the interconnecting network between characters were held constant. The appendix illustrates the scheme used to determine the number of groups in both the low and high overall density conditions.

Insert Figures 9 and 10 about here.

Figures 9 and 10 illustrate the low and high overall density conditions. In the low density condition, six applicant profiles were presented on the screen at a time and overall density was 240 characters or 12.5% of the total frame. On the other hand, in the high density condition, fifteen profiles were presented on the screen at a time and overall density was 606 characters or 31.5% of the total frame.

Apparatus. All material was displayed using an IBM PC-jr with color graphics monitor. Screening for color-blindness and binocular visual acuity was done with a Bausch & Lomb Modified Ortho-rater (cat. # 71-21-31-02).

Procedure. Before initiating a session, subjects were tested for color-blindness and visual acuity. Those subjects who tested as color weak or had poorer than 20/30 corrected visual acuity were given their extra credit and did not complete the rest of the experiment. Subjects who met the visual criteria were then told that they were playing the role of a personnel officer in a large corporation. Their task was to review job applicants on four different dimensions and then select the applicant with the highest score on the skill dimension. Instructions given to the subjects were the same for both Experiments 1a and 1b. Subjects were told that they would complete the procedure twice, once with one of the dimensions highlighted in red and once with all the dimensions appearing in the same color.

After two practice trials, subjects depressed the "enter" key on the computer keyboard to initiate the actual trials. Depressing the enter key also activated an internal counter to record the

subjects' response time. When the subjects identified the applicant with the highest skill score, they depressed the enter key again. This stopped the counter and also erased the information on the screen. The subjects then recorded the corresponding applicant number on a response sheet. To initiate the next trial, subjects depressed the enter key again. Subjects were instructed to proceed through the trials as fast as they could while keeping errors at a minimum. In order to minimize response time, subjects were told to keep their index fingers on the enter key throughout the experiment. This procedure was followed for 60 trials and the response times and number of errors were recorded for each subject.

Results

The results were analyzed separately for Experiment 1a – when hue was relevant to the task, and Experiment 1b – when hue was irrelevant to the task. Within each experiment, search times were analyzed using a 2 x 2 x 3 ANOVA with overall density (high vs. low) as a between-subjects variable, and presence of hue (no hue vs. hue) and trial block(1, 2, 3) as within-subjects variables. Due to a floor effect on error rate, an analysis of the data was not conducted in the relevant hue phase (Exp. 1a, 2a, 3a) of all three experiments.[1]

Relevant Hue. There was a significant main effect for overall density, $F(1,28) = 33.62$, $p < .0001$. Subjects took an average of 1.5 secs per trial to locate the target stimulus in the low overall density condition and an average of 2.75 secs per trial in the high overall density condition. The main effect for hue was significant, $F(1,28) = 101.39$, $p < .0001$. The mean search time per trial was 2.6 secs in the no hue condition and 1.6 secs in the relevant hue condition. There was also a significant main effect for trial block, $F(2,56) = 46.51$, $p < .0001$. Search times decreased across trial blocks, from 2.4 secs in the first block, to 2.1 secs and 1.9 secs in the second and third blocks. These data are summarized in Table 1.

Insert Table 1 about here.

The interaction between overall density and hue was significant, $F(1,28) = 26.8$, $p < .0001$.The presence of relevant hue affects search time more for the high overall density (a decrease of 1.4 secs per trial) than low overall density (a decrease of 0.5 secs per trial). All other two-way interactions

were not significant at the $p < .05$ level. The three-way interaction among hue, overall density and trial block was significant, $F(2,56) = 3.19$, $p < .05$. Inspection of Figure 11 suggests that the effect of practice was more evident comparing no hue to relevant hue (Exp. 1a) under levels of high overall density than low overall density.

Insert Figure 11 about here.

Irrelevant Hue. When the presence of hue was irrelevant to the task, the results of a 2 x 2 x 3 mixed design ANOVA showed a main effect for overall density, $F(1,28) = 233.68$, $p < .0001$; the presence of hue, $F(1,28) = 31.79$, $p < .0001$; and trial block, $F(2,56) = 4.12$, $p < .05$. Subjects took a greater amount of time to locate the target stimulus in the high overall density condition (3.00 secs per trial) than in the low overall density condition (2.51 secs per trial). Likewise, subjects took longer in the irrelevant hue condition (3.87 secs per trial) than in the no hue condition (1.65 secs per trial). The mean search time for block 1 was 2.8 secs per trial, while it was 2.7 secs for both blocks 2 and 3. The mean search times across all trials are listed in Table 1. There was also a statistically significant interaction between hue and overall density, $F(1,28) = 17.12$, $p < .001$. Comparing the no hue to the irrelevant hue condition, subjects took a substantially longer amount of time to locate the target stimulus in the high overall density condition (2.58 secs per trial) than in the low overall density condition (1.86 secs per trial).

There was also a significant interaction between hue and trial block, $F(2,56) = 65.12$, $p < .0001$. The difference between the no hue and the irrelevant hue conditions increased from block to block. The effect for irrelevant hue was not significant at block 1; however, it was significant at both block 2, $F(2,56) = 29.87$, $p < .001$, and at block 3, $F(2,56) = 85.19$, $p < .0001$. The two-way interaction between overall density and trial block, as well as the three-way interaction were not significant at the $p < .05$ level.

Insert Figure 12 about here.

Because of a floor effect on error rate, the data were aggregated across trial blocks, and the mean number of errors per sixty trials were analyzed using a 2 x 2 ANOVA with overall density as a between subjects variable, and the presence of hue as a within subjects variable. The results showed a significant main effect for overall density $F(1,28) = 7.80, p < .01$. In attempting to report the applicant with the highest skill score, subjects made an average of 2.2 errors in the low overall density condition and 3.4 errors in the high overall density condition. The main effect for hue was also significant, $F(1,28) = 107.86, p < .0001$. The mean number of errors was 1.00 for the no hue condition and 4.57 for the irrelevant hue condition. The mean number of errors across the sixty trials is presented in Table 2. There was also a reliable interaction between hue and overall density, $F(1,28) = 6.87, p < .05$. The increase in error rate from no hue to the presence of an irrelevant hue was greater in the high overall density condition(4.47 per sixty trials) than in the low overall density condition (2.67 per sixty trials).

Insert Table 2 about here.

Discussion

The addition of a relevant hue led to greater decreases in search time under conditions of high overall density as opposed to low overall density. This confirms our hypothesis concerning the interaction between hue and overall density and is consistent with previous research (Carter, 1979, 1982). Highlighting the target dimension reduced search time by 42% in the high overall condition and by 29% in the low overall condition; however, the mean search time per trial in the hue condition was still significantly lower under levels of low overall density. This apparent advantage of the low overall density condition only applies to single screen comparisons. When an operator is required to process information requiring more than one distinct screen, the presence of hue in the high overall density condition would prove more advantageous. Take for instance the following example – an operator is given the task of selecting the best candidate out of a pool of sixty applicants. Since the low overall density condition only allows six applicant profiles to be displayed per screen, the operator must view a total of ten distinct screens. Therefore, the total viewing time based on the results obtained in this experiment would be approximately 12.5 secs (calculation is

based on mean search time per trial in the low density-hue condition obtained from Table 1 – 1.25 secs per screen x 10 screens). On the other hand, information displayed via the high overall density condition would allow fifteen applicant profiles to be displayed per screen. This would require the operator to view just four distinct screens resulting in a total viewing time of approximately 8.1 secs. This advantage of the high overall density hue condition would also increase as the number of profiles to be viewed by the operator increases. Furthermore, as the total number of profiles to be processed increases, so does the number of distinct screens requiring the operator's attention. This means that in conditions of low overall density, the operator has to commit more information to memory and is susceptible to committing more errors. Therefore, it would be more advantageous to the screen designer to use relevant hue as an enhancement code when the amount of information per screen is at a optimal level. This advantage was also shown to increase as a function of practice. As the subject becomes increasing familiar with the task, this difference in total search time between the high and low overall density conditions would become even greater.

When hue was irrelevant, the presence of hue may have caused perceptual inhibition in the locating and reporting of the target applicant. Going from no hue to the presence of an irrelevant hue increased search time by 108% in the low overall density condition and by 179% in the high overall density condition. The number of errors increased at even greater rates than did search time. As compared to the presence of no hue, the addition of an irrelevant hue increased error rate by 250% in the low overall density condition and by over 400% in the high overall density condition. It was interesting, however, that neither search time or error rate differed significantly in the low versus high overall density no hue conditions.

Due to these dramatic increases in both search time and error rate, a stipulation must be placed on the recommended use of hue as an enhancement code under high levels of overall density. If the addition of hue could at any time result in an irrelevant dimension being highlighted, the subsequent increases in both search time and error rate offer strong evidence for the use of monochromatic (no hue) displays. That is, screen designers seeking to maximize the amount of displayed information should exercise caution when considering hue as an enhancement code.

Experiment 2

Method

Subjects and Design. Sixty undergraduate students at Virginia Tech participated in this experiment for extra credit. Sessions approximated 30 minutes in length and all subjects were tested individually. This experiment was also divided into two parts (Experiment 2a and 2b) depending on whether hue was relevant or irrelevant to the task. Within each experiment, subjects were assigned to one of two density conditions (low or high local density) and then required to complete the visual search task following the same procedure outlined in Experiment 1.

Procedure. The task was the same as in Experiment 1. That is, subjects reviewed job applicants on four different dimensions. The only difference being that local density was manipulated instead of overall density. Figures 13 and 14 illustrate the low and high local density conditions. In the low density condition, six profiles were presented on the screen at a time. Because the spatial position of the skill dimension varied from trial to trial, local density also varied. The mean local density was 14.84% with a standard deviation of 2.34% and a range of 11.51% (fourth position) to 16.91% (third position). In the high density condition, six profiles were again presented on the screen at a time and local density had a mean value of 38.12% with a standard deviation of 3.17% and a range of 34.53% (fourth position) to 42.44% (second position). Both overall density and grouping were held constant. Specifically, overall density was 240 characters or 12.5% of the total frame (optimal overall density – Danchak 1976; Smith, 1982), and both conditions consisted of 6 groups with 40 characters in each group (see appendix).

Insert Figures 13 and 14 about here.

Subjects were again required to search the profiles displayed on the CRT for the applicant with the highest skill score. As in the previous experiment, subjects were instructed to proceed through the trials as quickly as they could while keeping their error rate to a minimum. Search time and error rate were then recorded for each subject.

Results

As in the previous experiment, separate ANOVAs were conducted for relevant hue (Exp. 2a) and irrelevant hue (Exp. 2b). Within each experiment, search time data were analyzed using a 2 x 2 x 3 ANOVA. Local density (high vs. low) was a between-subjects variable, and both the presence of hue (no hue vs. hue) and trial block were within-subjects variables.

Relevant Hue. The effect of hue was statistically significant, $F(1,28) = 131.43, p < .0001$. Subjects took longer to locate the target stimulus in the no hue condition (1.79 secs per trial) than in the relevant hue condition (1.11 secs per trial). The effect for trial block was also significant, $F(1,28) = 62.05, p < .0001$. In block 1, subjects averaged 1.7 secs per trial in locating the target, 1.4 secs in block 2, and 1.3 secs in block 3.

Insert Table 3 about here.

An analysis of variance using the data in Table 3 showed the presence of a statistically significant interaction between hue and local density, $F(1,28) = 32.15, p < .0001$. Comparing the no hue condition to the relevant hue condition, search time decreased at a greater rate for the high local density condition (1.03 secs per trial) than for the low local density condition (0.35 secs per trial). Although the main effect for local density was not significant ($p = .58$), the effect for local density was significant in the no hue condition, $F(1,28) = 5.86, p < .05$. The other two-way interactions as well as the three-way interaction were not significant at the $p < .05$ level (see Figure 15).

Insert Figure 15 about here.

Irrelevant Hue. When hue was irrelevant to the visual search task, results of a 2 x 2 x 3 ANOVA showed a reliable main effect for hue, $F(1,28) = 7.26, p < .05$. It took subjects an average of 1.75 secs per trial to locate the target in the no hue condition 2.0 secs per trial in the irrelevant hue condition. There was also a statistically significant interaction between hue and trial block, $F(2,56) = 26.05, p < .0001$. The effect of hue was not significant at block 1, but was significant at

both block 2 and block 3, $p < .01$. All other two-way interactions as well as the three-way interaction were not significant at the $p < .05$ level (see Figure 16).

Insert Figure 16 about here.

Because of a floor effect on error rate, the data were aggregated across trial blocks, and the mean number of errors per sixty trials were analyzed using a 2 x 2 ANOVA with local density as a between subjects variable, and the presence of hue as a within subjects variable. The results showed only a main effect for hue, $F(1.28) = 33.31$, $p < .0001$. In attempting to report the applicant with the highest skill level, subjects made an average of 1.27 errors in the no hue condition and 4.9 errors in the irrelevant hue condition. All other effects were not statistically significant at the $p < .05$ level. Table 4 contains the mean number of errors for the four conditions.

Insert Table 4 about here.

Discussion

In Experiment 2, the differences in search time and error rate between high and low levels of local density were not statistically significant in both the relevant- and irrelevant-hue phases of the experiment. As previously stated, the relationship between local density and performance is a U-shaped function. It appears that in this experiment, we may have sampled from both sides of the minimum, failing to operationalize the optimum level of local density. It may be that the greater number of eye fixations required in the low local density condition could have counteracted the perceptual confusion between a target and background caused by tightly packing items in the high local density condition. However, the addition of a relevant hue reduced search time by 49% in the high local density condition and only 23% in the low local density condition. In fact, the difference between mean search time in the low density hue condition and the high density hue condition was not statistically significant. This interaction between the presence of relevant hue and local density may be, in part, due to how we operationalized low and high local density. Low levels of local density lead to increases in search time because of a *physical* separation between characters,

thus requiring a greater number of eye fixations to encode the data (Swanston & Walley, (1984). High levels of local density lead to increases in search time because of *perceptual* interference between the target and non-target areas within the 5 deg visual angle subtended off the central foveal area of the retina (Danchak, 1976; Egeth et al., 1973). Therefore, the addition of a relevant hue may have served to reduce the perceptual confusion in the high local density condition, but may have done little in reducing the physical separation between characters in the low local density condition. This idea is consistent with the Gestalt organizational principle of contrast. According to this principle, a perfectly homogenous field appears as a total field (*Ganzfeld*). To affect a segregation within this field requires a relatively strong differentiation between an object and its background (Wertheimer, 1923/1958). Such a differentiation can be achieved with the addition of hue. In our example, the total field is the 41.8mm circle subtended onto the screen of the CRT. Highlighting the target dimension serves to maximize the contrast between the target and its surrounding area under levels of high local density. In the low local density condition, the greater physical separation of characters causes the total field to be less homogeneous. The high local density field is composed of alphanumeric symbols, one of which is highlighted in red. The low local density field is made up of a mixture of alphanumeric symbols and blank space, therefore reducing the effectiveness of the red contrast.

The addition of an irrelevant hue seems to affect both conditions of local density in a similar fashion. Search time increased approximately 10% when going from no hue to the presence of an irrelevant in the low local density condition and 18% in the high local density condition. Error rate increased at a greater rate, but did not differ from one level of local density to the other. It appears that the presence of an irrelevant hue caused a deterioration in the reporting of the target response in both conditions, but more research is necessary to determine why both conditions of local density are equally affected. In conclusion, the minimal decrement experienced by hue being task-irrelevant strengthens the recommendation of hue as an effective enhancement code. More important, the addition of relevant hue allows the screen designer to display a greater amount of information within a smaller amount of space. This is especially relevant for smaller, more compact display monitors than the standard 24 x 80 character CRT. The use of hue as an enhancement code

allows the target to be presented within its surrounding environment without perceptually overloading the operator.

Experiment 3

Method

Subjects and Design. Sixty undergraduate students participated in this experiment for extra credit. Subjects were tested individually and sessions lasted approximately 30 minutes. The experiment was divided into two experiments depending on whether hue was relevant (Exp. 3a) or irrelevant (Exp. 3b) to the task. Within each experiment, subjects were first assigned to one of two density conditions (grouped or ungrouped) and then completed the visual search task for both the no hue and hue conditions.

Procedure. The task was the same as that in the previous experiments except for screen format. On each trial, subjects were required to review several job applicant profiles and then select the applicant with the highest skill score. Subjects were instructed to go through the trials as fast as possible without guessing. Search time and error rate were recorded for each subject. Figures 17 and 18 illustrate the grouped and ungrouped conditions. In the grouped condition, 6 profiles were presented on the screen of an IBM PCjr at a time. Each screen consisted of 6 perceptual groups each with 37 characters (see appendix). In the ungrouped condition, 6 profiles were presented on the screen at a time. Each screen consisted of 1 perceptual group with 222 characters. In both grouping conditions, overall density and local density remained constant. Overall density was 222 characters or 11.56% of the total frame. The level of local density for both conditions had a mean value of 22.42% with a standard deviation of 0.13% and a range of 22.29% to 22.54%. experiments.

Insert Figures 17 and 18 about here.

Results

In both the relevant and irrelevant hue phase of this experiment, search time data were analyzed using a 2 x 2 x 3 ANOVA. Grouping (grouped vs. ungrouped) was a between-subjects

variable, and both the presence of hue (no hue vs. hue) and trial block were within-subjects variables.

Relevant Hue. There was a statistically significant main effect for hue, $F(1,28) = 145.25$, $p < .0001$. Subjects took an average of 2.03 secs per trial to locate the target in the no hue condition and 1.19 secs in the relevant hue condition. There was also a significant main effect for trial block, $F(2,56) = 65.20$, $p < .0001$. Average search time was 1.8 secs for block 1, 1.6 secs for block 2, and 1.2 secs for block 3.

Insert Table 5 about here.

An analysis of variance conducted on the data contained in Table 5 resulted in a statistically significant interaction between hue and grouping, $F(1,28) = 28.19$, $p < .0001$. The main effect for grouping was not significant because of the disordinal relationship between hue and grouping. In the no hue condition, search times were significantly lower when items were grouped, $F(1,28) = 7.27$, $p < .05$. In the relevant hue condition, just the opposite was found. Search times were significantly lower when items were ungrouped as opposed to being grouped, $F(1,28) = 7.27$, $p < .05$. All other interactions were not significant at the $p < .05$ level (see Figure 19).

Insert Figure 19 about here.

Irrelevant Hue. Results of a 2 x 2 x 3 ANOVA showed statistically significant main effects for grouping, $F(1,28) = 6.01$, $p < .05$; and hue, $F(1,28) = 7.49$, $p < .05$. It took subjects an average of 1.69 secs per trial to locate the target in the grouped condition and 1.98 secs per trial in the ungrouped condition. Mean search time per trial for the hue manipulations were 1.71 secs for no hue and 1.97 secs for irrelevant hue. There was also a statistically significant main effect for trial block, $F(2,56) = 16.91$, $p < .0001$. Subjects took an average of 1.9 secs in block 1 to locate the target, and 1.8 secs in both blocks 2 and 3. Figure 20 shows that the interaction between hue and grouping was statistically significant, $F(1,28) = 4.20$, $p < .05$. A comparison of the no hue condition

to the irrelevant hue condition showed an increase in the mean search time per trial of 0.50 secs in the grouped condition and 0.07 secs in the ungrouped condition.

Insert Figure 20 about here.

The interaction between hue and trial block was also significant, $F(2,56) = 39.08$, $p < .0001$. The difference between the no hue and irrelevant hue condition was not significant for block 1. It was, however, significant for both blocks 2 and 3, $p < .01$. The interaction between grouping and trial block as well as the three-way interaction were not significant at the $p < .05$ level (see Figure 20).

Insert Table 6 about here.

The mean number of errors per sixty trials are reported in Table 6. Because of a floor effect on error rate, the data were aggregated across trial blocks, and the mean number of errors per sixty trials were analyzed using a 2 x 2 ANOVA with grouping as a between subjects variable, and the presence of hue as a within subjects variable. The results showed a statistically significant main effect for grouping, $F(1,28) = 4.85$, $p < .05$; and for hue, $F(1,28) = 104.43$, $p < .0001$. While attempting to locate the target stimulus, subjects made an average of 2.80 errors in the grouped condition and 4.33 errors in the ungrouped condition. Mean error rate per sixty trials was 1.63 for the no hue condition and 5.50 for the irrelevant hue condition. There was also a reliable interaction between hue and grouping, $F(1,28) = 4.47$, $p < .05$. A comparison between the no hue condition and the irrelevant hue condition indicates an increase in the mean number of errors of 3.1 per sixty trials in the grouped condition and 4.7 in the ungrouped condition.

Discussion

The addition of a relevant hue decreased search time by 25% in the grouped condition and by 54% in the ungrouped condition. In fact, the mean search time per trial in the ungrouped hue condition was significantly lower than in the grouped hue condition. According to Attneave (1954) and Hochberg and McAlister (1953) a "good" figure contains less information than a bad one. If

information is divided by several axes of symmetry, the information processing load on the operator is lower, thus allowing information to be more easily processed and stored. This idea apparently holds true for the no hue conditions of grouped and ungrouped material. The separation of applicant profiles into six logically separated groups each with 37 characters resulted in lower search times than the compiling of profiles into a single group consisting of 222 characters. However, the addition of hue showed a completely reversed effect – search times in the ungrouped condition were significantly lower than those in the grouped condition. At first glance, this finding appears counter-intuitive, but it can be explained using the Gestalt organizational principles of proximity, similarity, and contrast.

According to Wertheimer (1923/1958), the principles of proximity, similarity, and contrast operate in a hierarchical fashion, the most basic being the principle of proximity. The principle of proximity states that items appearing closest to one another will tend to be grouped together. Wertheimer further states that given items of equal proximity, those items that are similar to one another will tend to be grouped together, thus the second principle. He goes on to state that when an object appears in a homogeneous field of similar items, a segregation between items can only be made by some form of contrast, say the use of hue. In the no hue grouped condition, items are separated into six distinct groups by virtue of the principle of proximity. However, in the no hue ungrouped condition, all items are of equal proximity, equal similarity (all alphanumeric symbols), and equal contrast. Therefore, the material can not be perceptually grouped and the resulting search times are significantly longer than the no hue grouped condition.

The addition of hue, however, may cause the grouped condition to be divided in terms of both proximity and contrast. According to Palmer (1982), figures which are grouped by both hue and proximity activate similar higher-order feature analyzers, thus resulting in problems with the integration of material. In the ungrouped condition, contrast is achieved by using hue to identify the relevant information. In the ungrouped condition, the influence of contrast (by hue marking) is impaired and may be made redundant by the differing proximal arrangements of items. Thus, the presence of hue as compared to no hue serves to facilitate performance (reduce search time) in the ungrouped condition, but the same effect fails to occur in the grouped condition.

Adding an irrelevant hue resulted in an increase in search time of 31% in the grouped condition, but only 3% in the ungrouped condition. Error rate, however, doubled in the grouped condition and tripled in the ungrouped condition. It seems that the effect of an irrelevant hue is more apparent in terms of the errors the operator commits. In this situation, there is again strong evidence that the presence of irrelevant hue impairs performance in both the grouped and ungrouped conditions. However, the greater contrast achieved by introducing hue in the ungrouped condition serves to heighten this effect in terms of error rate. Because of this, the screen designer must again exercise caution when using hue to highlight ungrouped material. If there is a chance that an irrelevant dimension might be highlighted, it would be more advantageous to group the material and display it using a monochromatic display monitor.

General Discussion

The results of Experiment 1a showed that the presence of relevant hue relative to no hue led to greater decreases in search time for the high overall density condition than for the low overall density condition. This difference was even more prevalent with practice. With the strengthening of the desired response, the facilitating effect of adding a relevant hue was more pronounced in the high overall density condition than in the low overall density condition. In Experiment 1b, comparison of the irrelevant hue and no hue conditions showed greater increases in search time and number of errors for the high overall density condition relative to the low overall density condition. The increase in search time when comparing irrelevant hue to no hue was also more prevalent with practice, with the greatest increases being at trial block 3.

In Experiment 2a, comparison of the relevant hue and no hue conditions indicated greater decreases in search time for the high local density condition than for the low local density condition. When hue was irrelevant to the task (Exp. 2b), increases in search time in the irrelevant hue condition relative to the no hue condition were the greatest at block 3, followed by block 2 and then block 1.

Comparison of the relevant hue and no hue conditions in Experiment 3a showed greater decreases in search time for the ungrouped condition relative to the grouped condition. Without hue, times were significantly lower in the grouped condition, while with relevant hue the lower times were associated with the ungrouped condition. As in the previous two experiments, the

results of Experiment 3b showed that the increase in search time when comparing irrelevant hue to no hue was greatest in block 3, followed by block 2 and then block 1. With respect to the number of errors committed, there was a greater increase when comparing irrelevant hue to no hue in the ungrouped condition than in the grouped condition.

In all three experiments, comparison of the relevant hue and no hue conditions showed red hue to be an effective enhancement code. The greatest reduction of search time was in the relevant hue-high overall density condition of Experiment 1a. This finding is consistent with previous research done on the combined effects of hue and overall density (Carter, 1979; Noble & Sanders, 1980; Luder, 1984). That is, the advantage (in terms of decreasing search time) the hue coded display has over the monochromatic display increases as overall density increases.

In all three experiments, more errors were committed when hue was irrelevant to the task relative to the no hue condition. However, the only significant increases in search time due to irrelevant hue were in Experiment 1b, with the greater increase in search time being in the high overall density condition. It appears then that the mechanisms for search time and number of errors operate differently when hue is irrelevant to the task. With respect to search time, it seems that only the total amount of information on the screen (overall density) affects performance. In Experiments 2b (local density) and 3b (grouping), overall density was the same, both within and across experiments (approximately 12.5% of the total screen). Therefore, the spacing between items as well as the total number of groups does not appear to affect search time when the presence of hue is irrelevant to the task. With respect to the number of errors, it appears that all three definitions of display density affect performance when hue is irrelevant to the task. It is difficult to determine whether this impairment is due to perceptual inhibition in the encoding of the target response or response competition in the reporting of the target because of the task itself. The task involved two steps: finding the applicant with the highest skill score, and then reporting the corresponding applicant number. Therefore, the presence of an irrelevant hue could have caused an error in the encoding of the highest skill score or in the reporting of the applicant number, either of which would have resulted in an incorrect response.

One unexpected finding was the reoccurring interaction between irrelevant hue and trial block. In all three experiments, search times either decreased or stayed the same from trial block to trial

block in the no hue condition. However, in the irrelevant hue condition of all three experiments, there was a consistent increase in search time from block to block. It appears then that practice served to heighten the impairing effects of irrelevant hue. As the number of trials increased, the impairing effect of the irrelevant hue in all three experiments also increased.

Because of the facilitating effect of relevant hue and the impairing effect of irrelevant hue in all three experiments, it appears that the purpose of hue (relevant – irrelevant) is crucial in determining the effectiveness of hue as an enhancement code. However, this research used a simple visual search and identification task. More research is needed to find out if this conclusion can be generalized to more complex tasks, and to response measures other than speed and accuracy. It should also be noted that only red hue was manipulated in all three experiments. More research is necessary in order to find out if other hues or combinations of hues provide similar effects (e.g., Bevans & Dukes, 1953; Grundlach & Machoubrey, 1931; Wallis, 1935).

The effects of the three display density definitions were not as straightforward as those of hue. There was a reliable effect for overall density in Experiments 1, which supports the previous claims concerning the optimal levels of overall density (15% of the screen – Danchak, 1976; Smith, 1982). However, the results of the density manipulations in both Experiment 2 and 3 were inconsistent and visual inspection of the high local density screen (Figure 14) and the grouped screen (Figure 17) shows some similarities. It is possible that grouping and local density are simply two different methods of measuring the same construct, that of screen layout or screen complexity. Also, the recommendations concerning the use of hue in the ungrouped conditions of Experiments 3a and 3b need some clarification since the term "ungrouped" is really a misnomer. It would be more appropriate to refer to this condition as one in which all items were formatted in a equidistant arrangement and were similar in form and content (all were alphanumeric symbols). According to Treisman (1982), items do not have to be of equal proximity to be labeled ungrouped. Futhermore, as the complexity of the screen design increases, it becomes increasingly difficult to use labels such as grouped and ungrouped. Therefore, any recommendations based on the results of Experiments 3a and 3b should be viewed in terms of the specific manipulations used in the experiments.

The results of these experiments also have some implications for the Gestalt organizational principles of proximity, similarity, and contrast. The significant effect of hue, both relevant and

irrelevant, across all three experiments supports the notion that these three principles are arranged in some hierarchical fashion with contrast being the most important of the three (Wertheimer, 1923/1958). According to Wertheimer (1923/1958), the greatest contrast occurs when items are of equal proximity and equal similarity. The greater decrease in search time in the relevant hue-ungrouped condition of Experiment 3a and the greater increase in search time in the irrelevant hue-ungrouped condition of Experiment 3b appear to support Wertheimer's claim. The inferiority of the grouped condition to the ungrouped condition in terms of the contrast achieved by the presence of hue supports Palmer's (1982) claim that items grouped by both proximity and contrast (grouped condition) activate similar higher order feature analyzers, which in turn results in problems with the integration of material.

In conclusion, the use of hue as an enhancement code is more task specific than Christ (1975, 1977) originally suggested. Besides varying with practice, the complexity of the task, and the type of response measured, its effectiveness is dependent on the specific manipulation of display density and more importantly on its relevance to the task. Hue cannot be globally recommended as an effective enhancer and should only be used when the specific application warrants its usage. Specifically, the contrast achieved by using hue is most benefical to performance when its usage is relevant to the task and a large amount of information needs to be presented at one time.

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Footnotes

[1]There was a floor effect on error rate in the relevant hue phase of each experiment. All subjects reached a criterion of 95% correct. Therefore, the error data for the relevant phase of all experiments were not statistically analyzed.

Table 1.

Mean Search Times (in secs) Under High and Low Overall Density for No Hue & Relevant Hue Conditions of Exp. 1a and No Hue & Irrelevant Hue Conditions of Exp. 1b.

	Experiment 1a		Experiment 1b	
Overall Density	No Hue	Relevant Hue	No Hue	Irrelevant Hue
Low	1.71	1.25	1.59	1.71
High	3.47	2.03	3.45	4.29

Table 2.

Mean Number of Errors for 60 Trials Under High and Low Overall Density for No Hue & Irrelevant Hue Conditions of Exp. 1b.

	Experiment 1b	
Overall Density	No Hue	Irrelevant Hue
Low	0.87	1.13
High	3.53	5.60

Table 3.

Mean Search Times (in secs) Under High and Low Local Density for No Hue & Relevant Hue Conditions of Exp. 2a and No Hue & Irrelevant Hue Conditions of Exp. 2b.

	Experiment 2a		Experiment 2b	
Local Density	No Hue	Relevant Hue	No Hue	Irrelevant Hue
Low	1.50	1.16	1.77	1.95
High	2.10	1.06	1.73	2.04

Table 4.

Mean Number of Errors for 60 Trials Under High and Low Local Density for No Hue & Irrelevant Hue Conditions of Exp. 2b.

	Experiment 2b	
Local Density	No Hue	Irrelevant Hue
Low	1.67	5.27
High	0.87	4.53

Table 5.

Mean Search Times (in secs) Under Grouped and Ungrouped Density for No Hue & Relevant Hue Conditions of Exp. 3a and No Hue & Irrelevant Hue Conditions of Exp. 3b.

	Experiment 3a		Experiment 3b	
Grouping	No Hue	Relevant Hue	No Hue	Irrelevant Hue
Grouped	1.83	1.36	1.47	1.92
Ungrouped	2.24	1.03	1.96	2.02

Table 6.

Mean Number of Errors for 60 Trials Under Grouped and Ungrouped Density for No Hue & Irrelevant Hue Conditions of Exp. 3b.

	Experiment 3b	
Grouping	No Hue	Irrelevant Hue
Grouped	1.27	4.33
Ungrouped	2.00	6.67

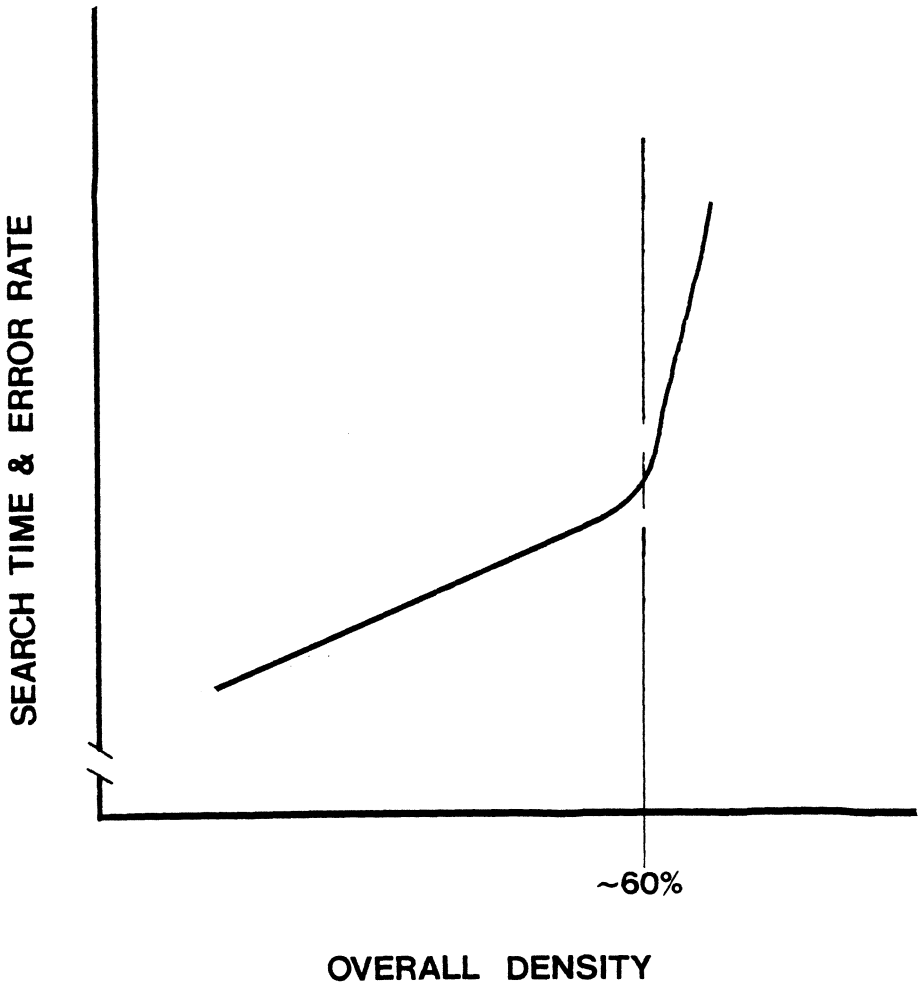

Figure 1. Schematic representation of the relationship between search time & error rate and overall density.

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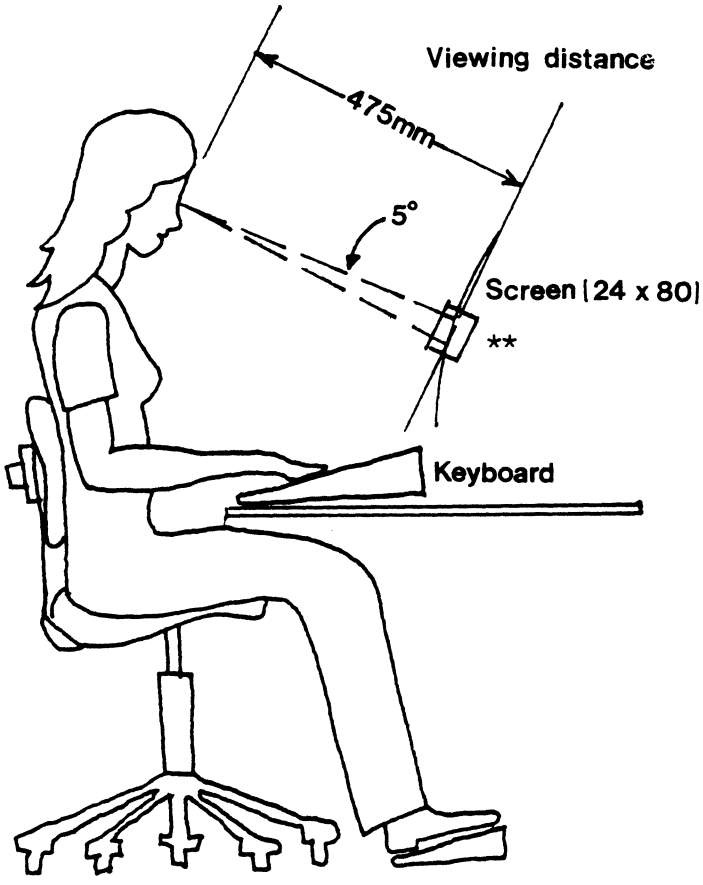
Figure 2. Two display screens with the same overall density but with different local density (after Tullis, 1983).



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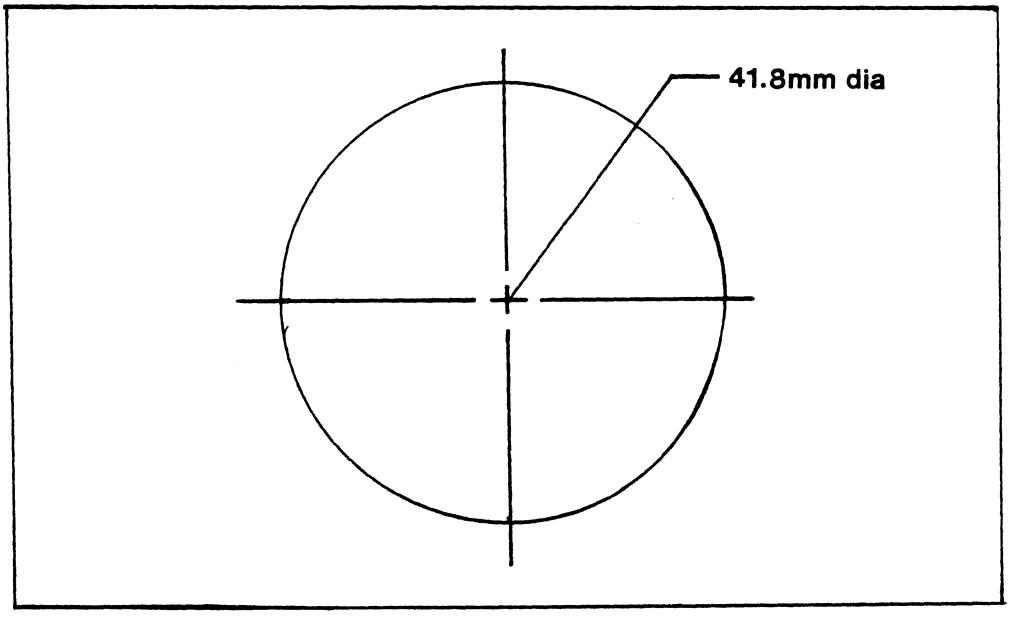


Figure 3. Recommended viewing distance and the circle of maximum visual acuity on a 24 x 80 character CRT (after Cakir et al., 1980 and Tullis, 1983).

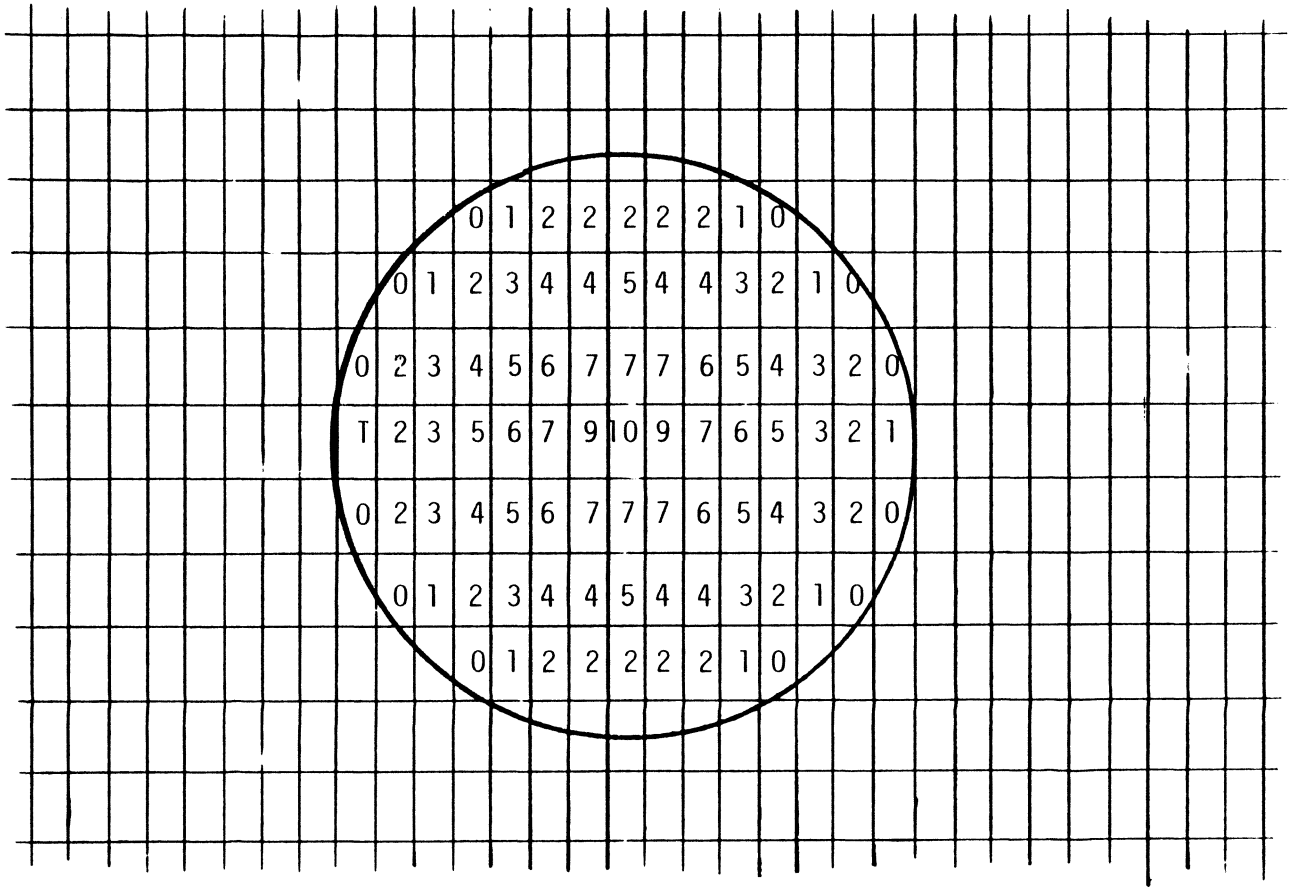


Figure 4. Character spacing on CRT subtended by the 5-deg visual angle and their approximate numerical weights (after Tullis, 1983).

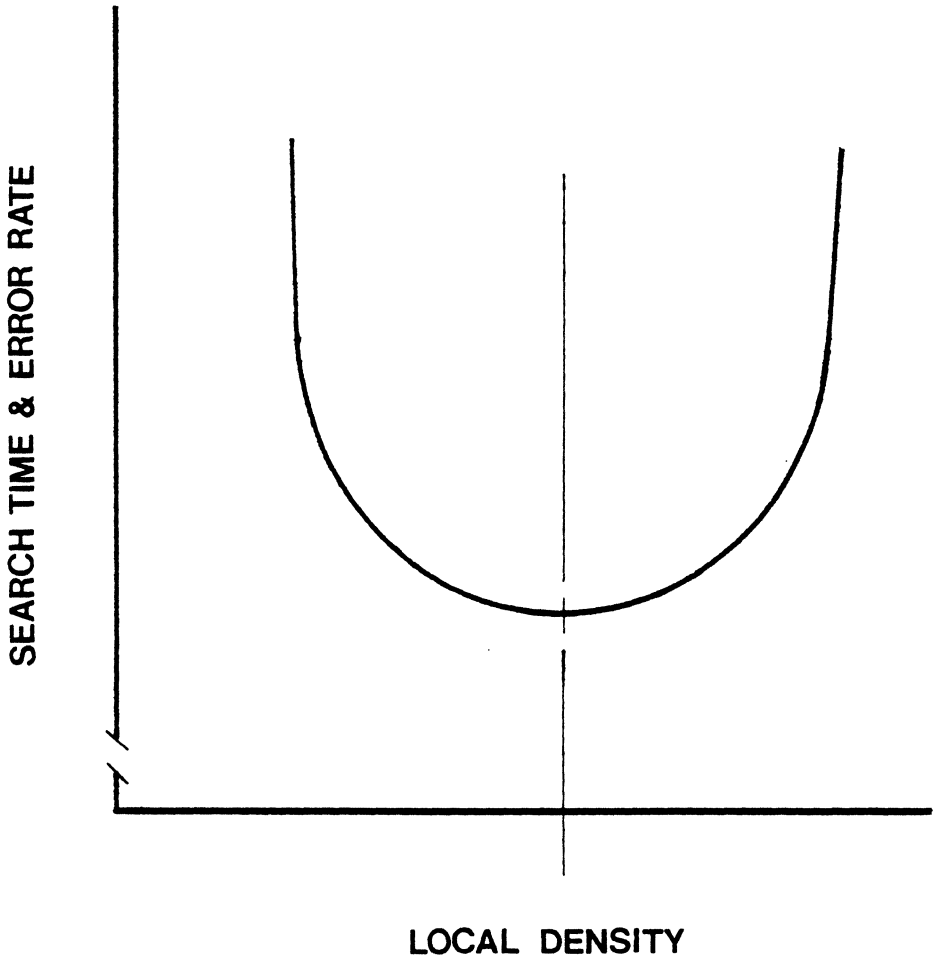


Figure 5. Schematic representation of the relationship between search time & error rate and local density.

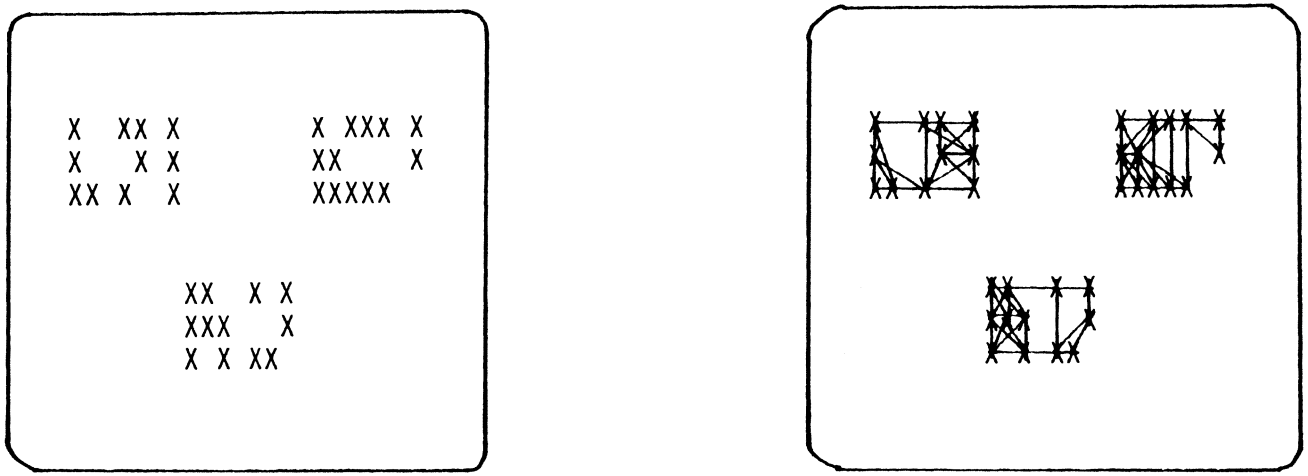


Figure 6. Sample CRT display and the interconnecting network used to define a group (after Tullis, 1983 and Zahn, 1971).

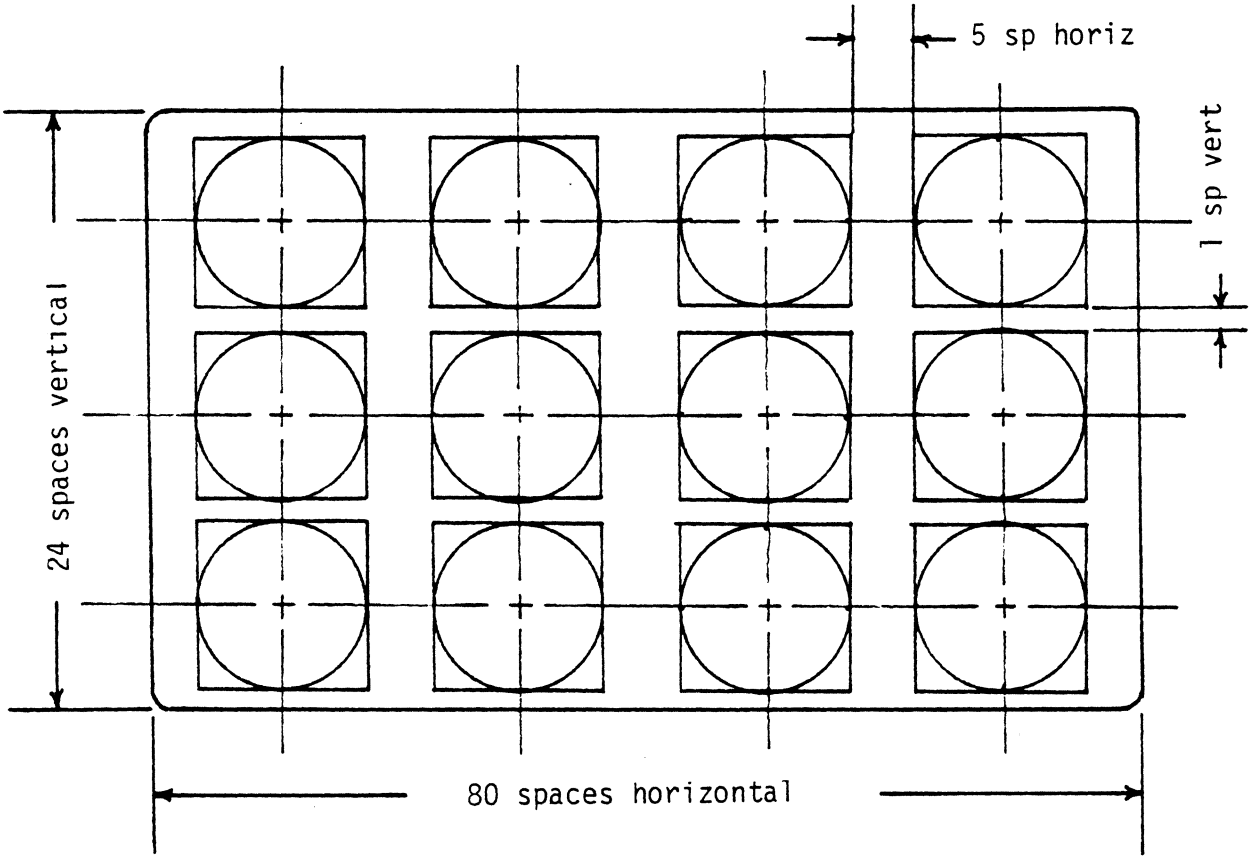


Figure 7. Recommended maximum number of groups each containing a maximum of 88 items for a standard 24 x 80 character CRT.

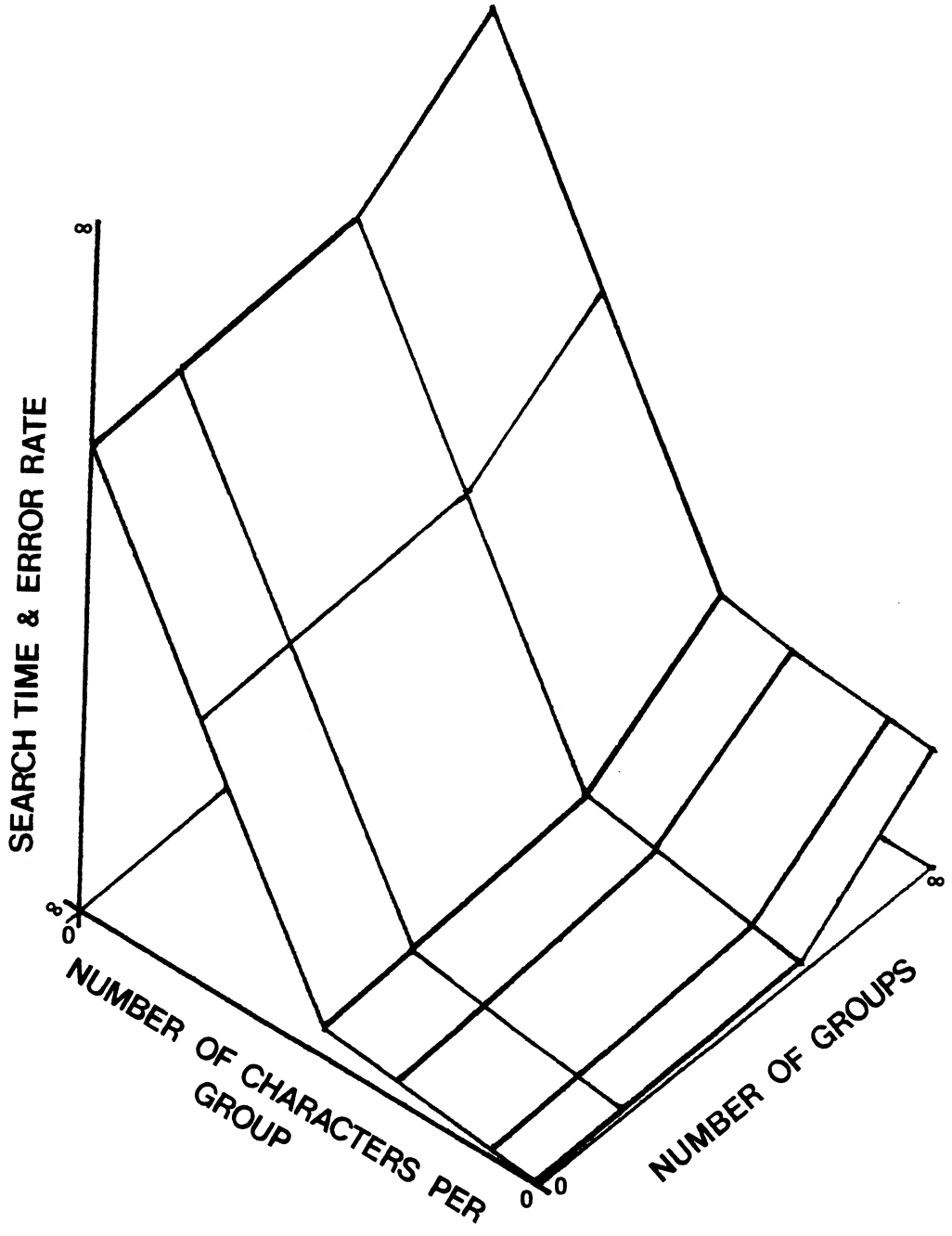


Figure 8. Schematic representation of the relationship between search time & error rate and the two components of grouping.

APPLICANT # 1		APPLICANT # 2		APPLICANT # 3	
MOTIV	21	MOTIV	26	MOTIV	27
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21

APPLICANT # 4		APPLICANT # 5		APPLICANT # 6	
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

Figure 9. Sample screen fo the low overall density condititon.

APPLICANT # 1		APPLICANT # 2		APPLICANT # 3		APPLICANT # 4		APPLICANT # 5	
MOTIV	27	MOTIV	21	MOTIV	26	MOTIV	27	MOTIV	27
IQ	23	IQ	20	IQ	25	IQ	22	IQ	27
EXPER	23	EXPER	27	EXPER	26	EXPER	25	EXPER	26
SKILL	28	SKILL	28	SKILL	29	SKILL	27	SKILL	20

APPLICANT # 6		APPLICANT # 7		APPLICANT # 8		APPLICANT # 9		APPLICANT # 10	
MOTIV	28	MOTIV	22	MOTIV	22	MOTIV	24	MOTIV	28
IQ	21	IQ	24	IQ	27	IQ	27	IQ	25
EXPER	25	EXPER	19	EXPER	26	EXPER	25	EXPER	22
SKILL	27	SKILL	25	SKILL	27	SKILL	25	SKILL	24

APPLICANT # 11		APPLICANT # 12		APPLICANT # 13		APPLICANT # 14		APPLICANT # 15	
MOTIV	26	MOTIV	23	MOTIV	26	MOTIV	25	MOTIV	23
IQ	23	IQ	26	IQ	22	IQ	24	IQ	23
EXPER	23	EXPER	27	EXPER	23	EXPER	26	EXPER	27
SKILL	21	SKILL	20	SKILL	20	SKILL	22	SKILL	24

Figure 10. Sample screen for the high overall density condition.

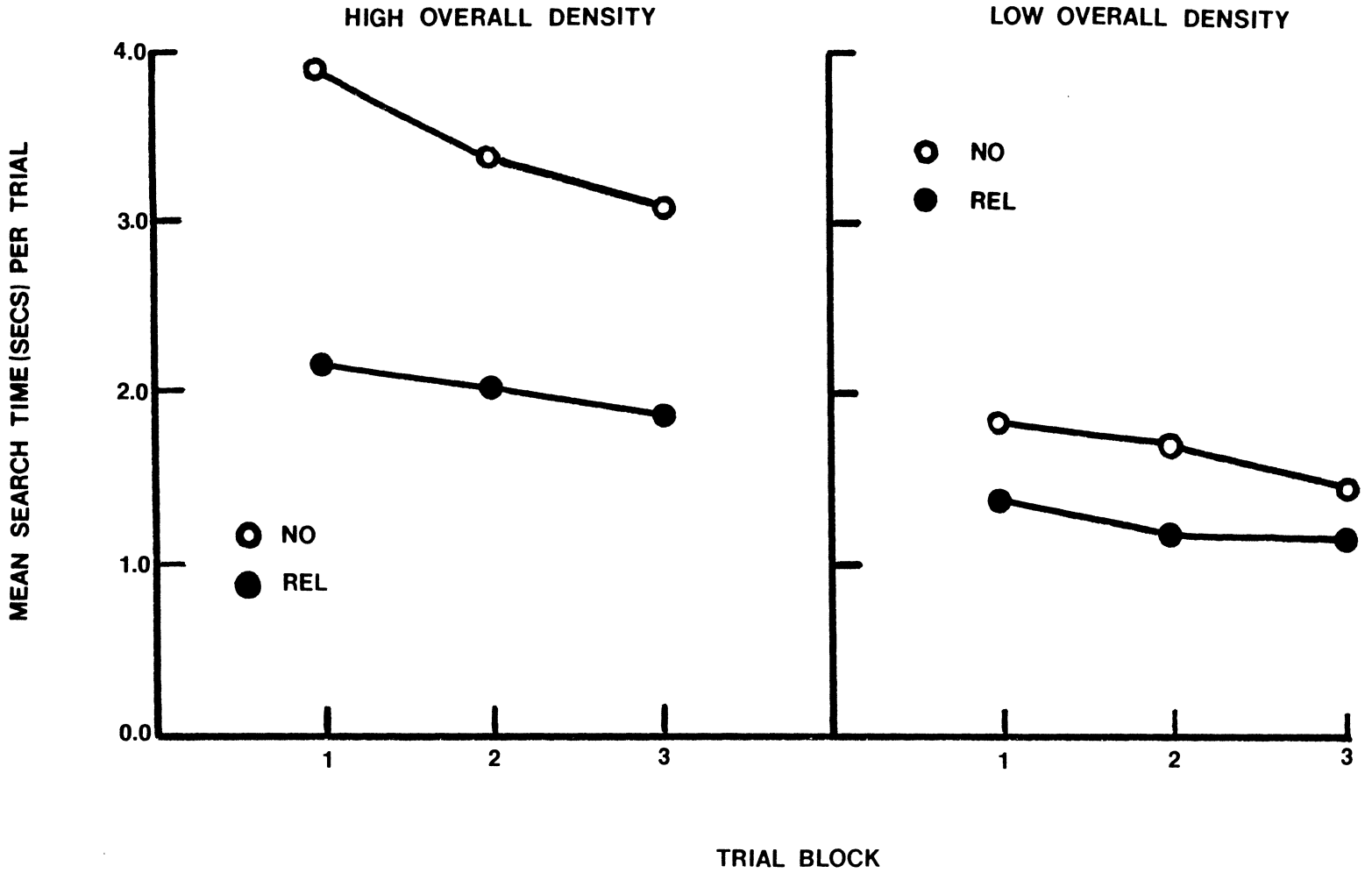


Figure 11. Mean search time on trial blocks 1-3 for the relevant (rel) hue and no hue conditions under high and low overall density.

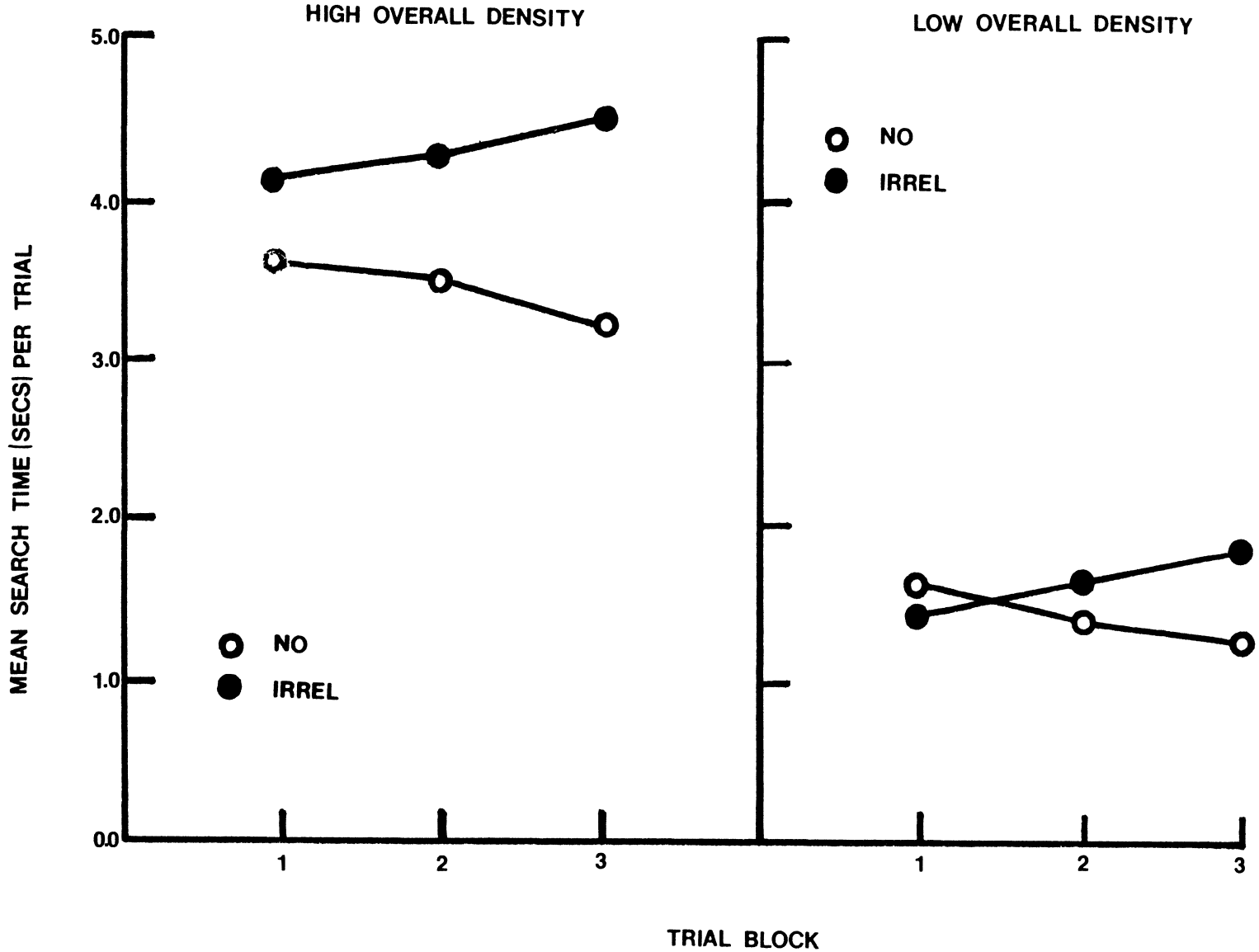


Figure 12. Mean search time on trial blocks 1-3 for the irrelevant (irrel) hue and no hue conditions under high and low overall density.

APPLICANT # 1		APPLICANT # 2		APPLICANT # 3	
MOTIV	31	MOTIV	26	MOTIV	31
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21

APPLICANT # 4		APPLICANT # 5		APPLICANT # 6	
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

Figure 13. Sample screen for the low local density condition.

APPLICANT # 1		APPLICANT # 2		APPLICANT # 3	
MOTIV	21	MOTIV	26	MOTIV	27
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21

APPLICANT # 4		APPLICANT # 5		APPLICANT # 6	
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

Figure 14. Sample screen for the high local density condition.

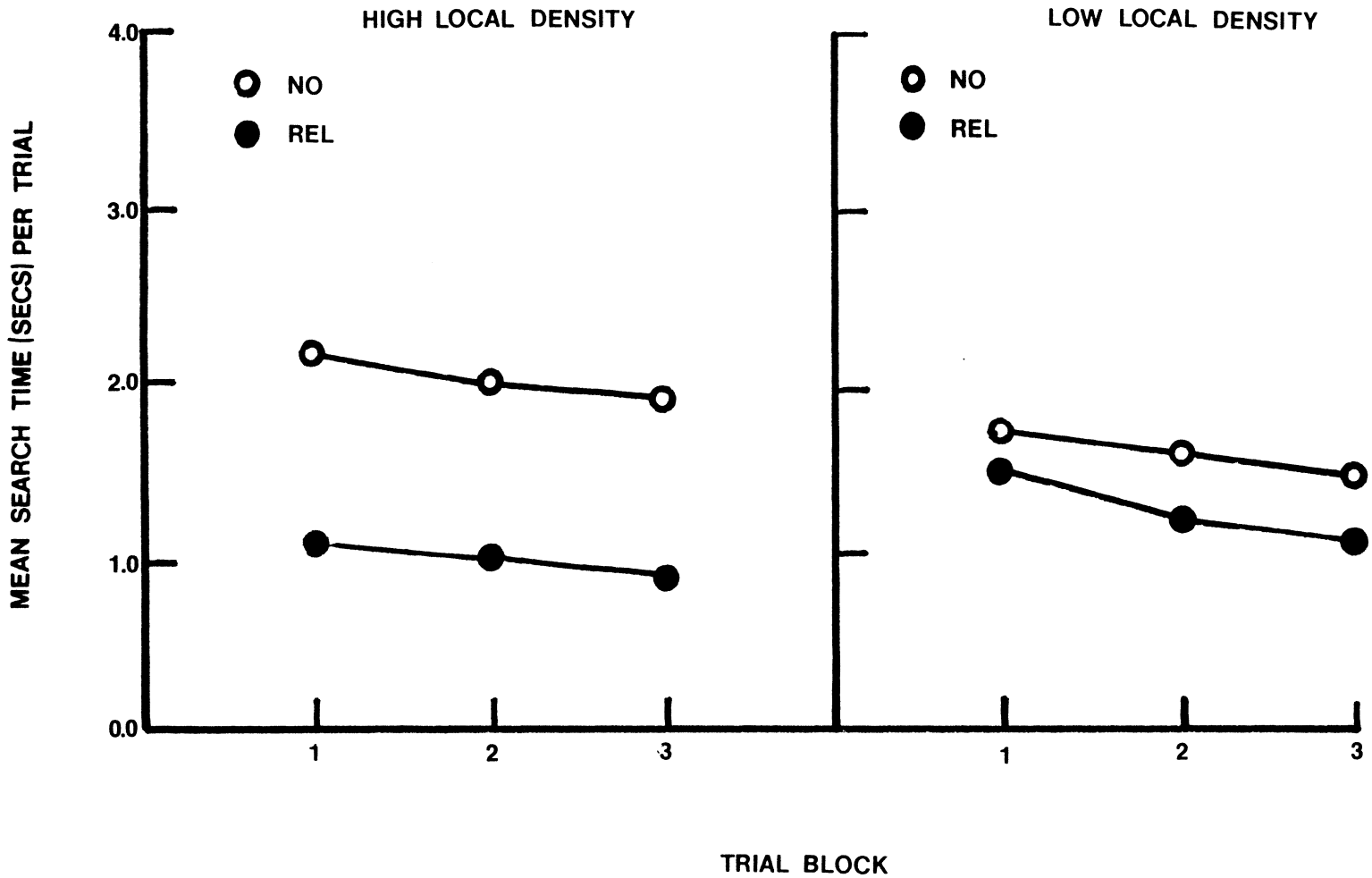


Figure 15. Mean search time on trial blocks 1-3 for the relevant (rel) hue and no hue conditions under high and low local density.

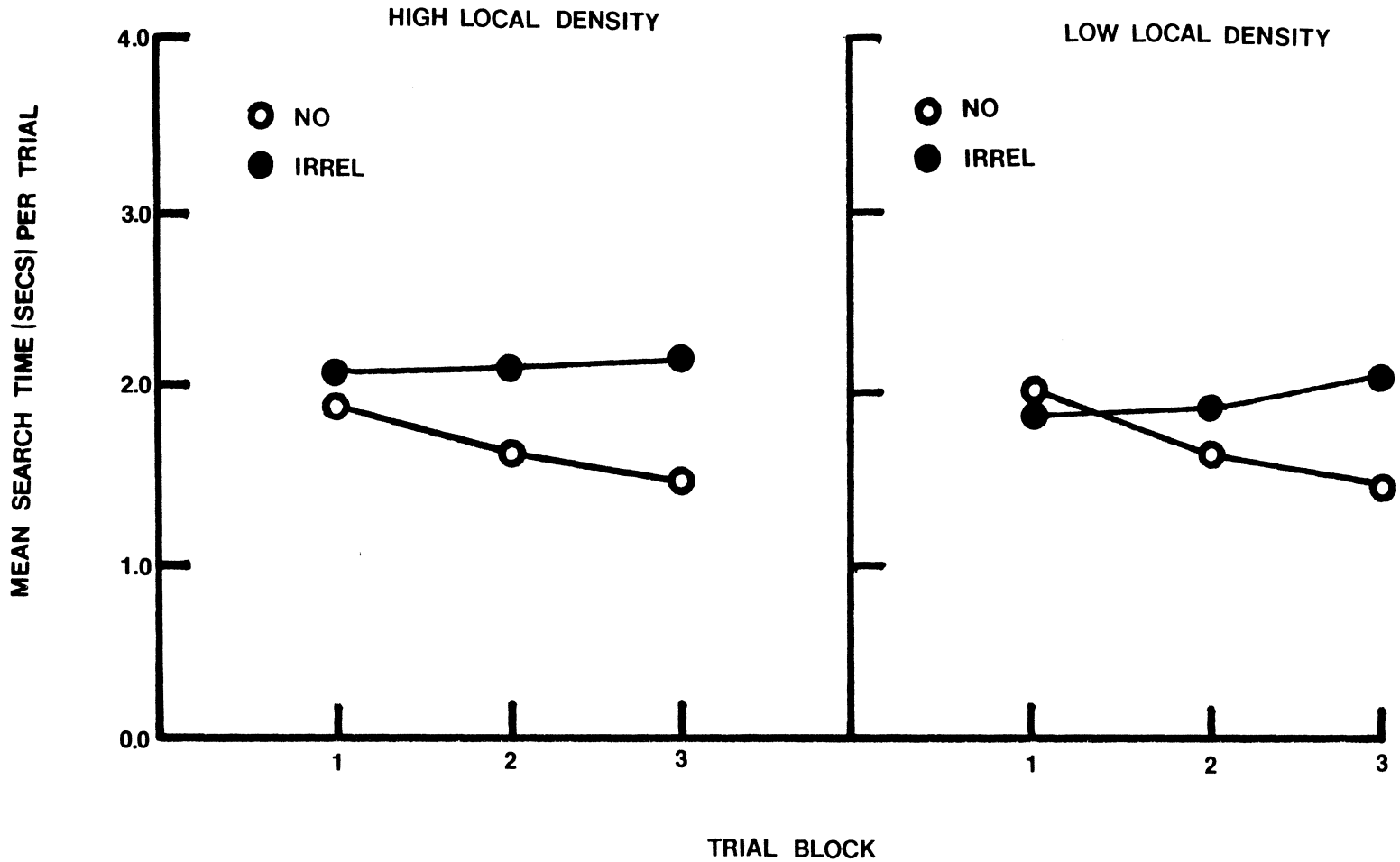


Figure 16. Mean search time on trial blocks 1-3 for the irrelevant (irrel) hue and no hue conditions under high and low local density.

PERSON # 1		PERSON # 2		PERSON # 3	
MOTIV	21	MOTIV	26	MOTIV	27
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21

PERSON # 4		PERSON # 5		PERSON # 6	
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

Figure 17. Sample screen for the grouped condition.

PERSON	# 1	PERSON	# 2	PERSON	# 3
MOTIV	21	MOTIV	26	MOTIV	27
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21
PERSON	# 4	PERSON	# 5	PERSON	# 6
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

Figure 18. Sample screen for the ungrouped condition.

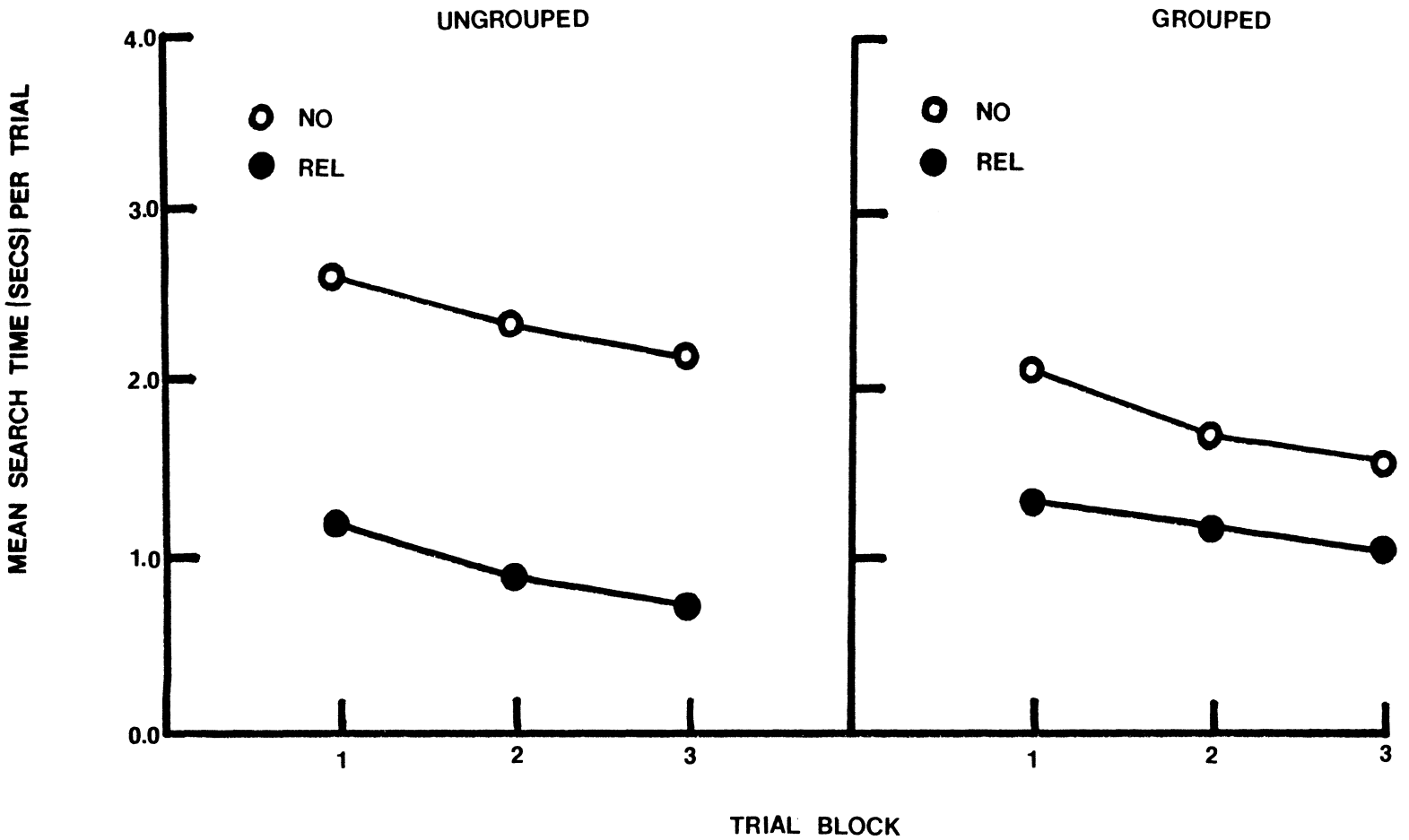


Figure 19. Mean search time on trial blocks 1-3 for the relevant (rel) hue and no hue conditions under grouped and ungrouped density.

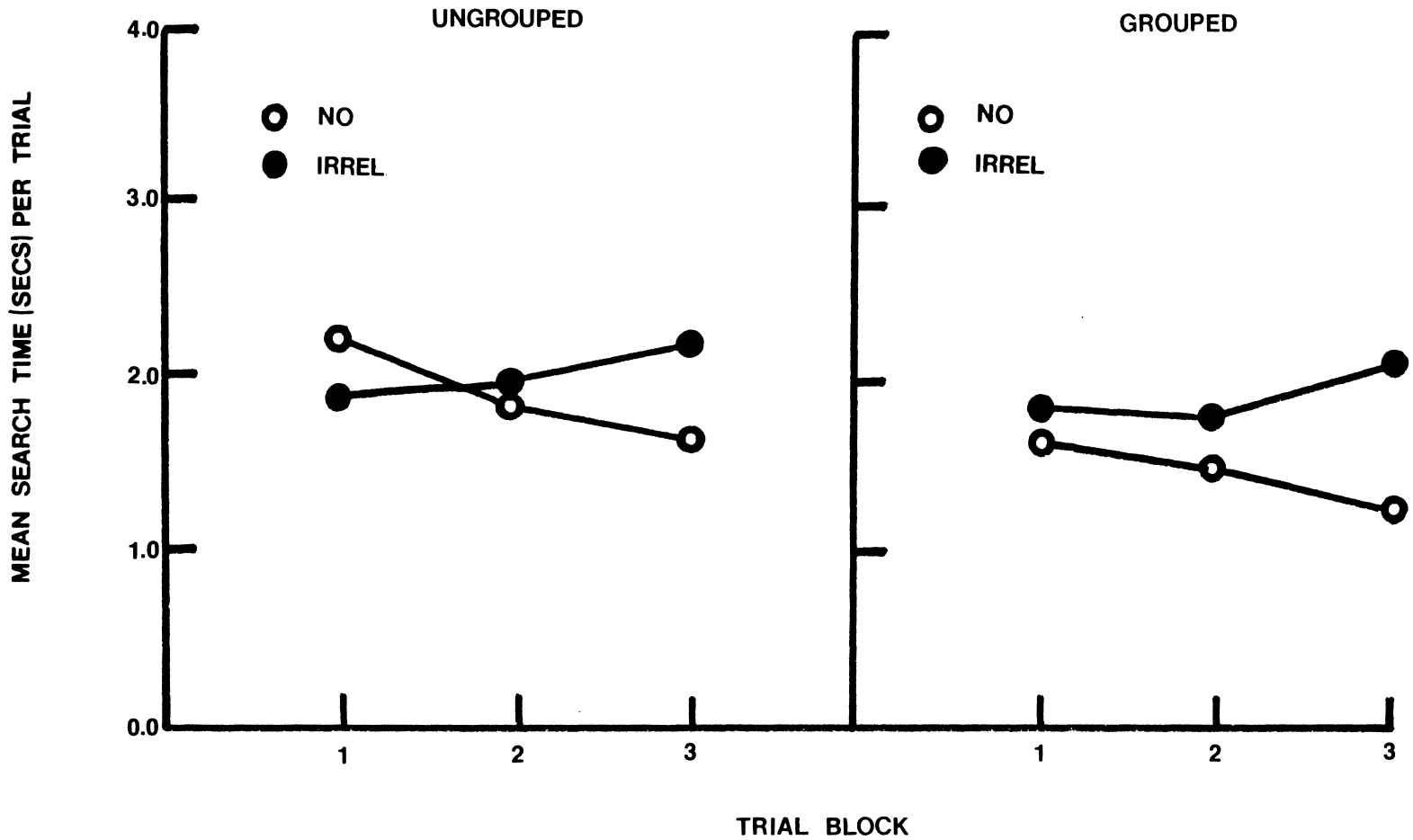


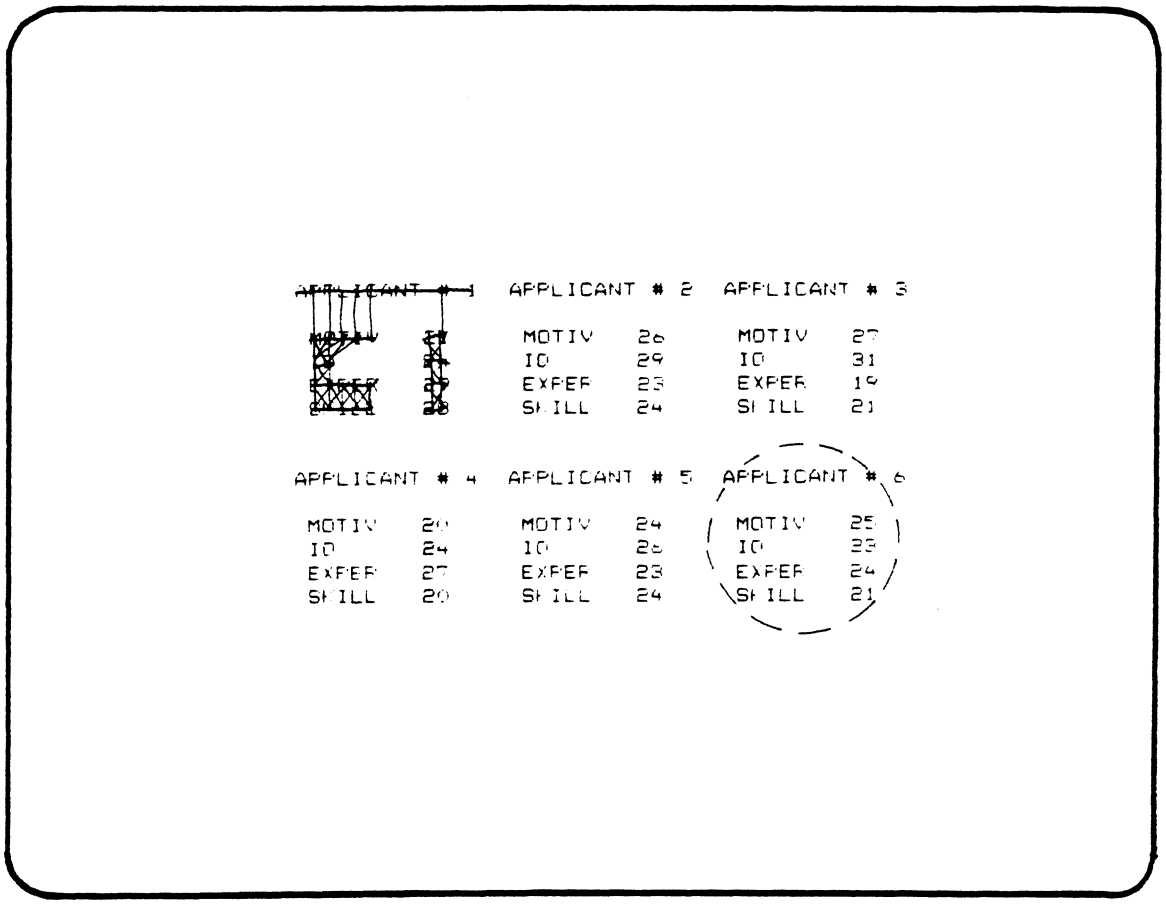
Figure 20. Mean search time on trial blocks 1-3 for the irrelevant (irrel) hue and no hue conditions under grouped and ungrouped density.

Appendix

Grouping Networks for all Density Manipulations

Zahn (1971) developed a technique for illustrating the number of perceptual groups contained in any display based on the Gestalt organizational principle of proximity. The procedure for generating grouping networks is as follows: first, calculate the mean distance between a character and its nearest neighbor – both horizontally and vertically. Then form a graph by connecting those symbols that are closer than the calculated mean values. A group is then defined as any interconnecting set of symbols.

This appendix contains the resulting grouping networks for each of the six density manipulations used in this paper. Also, the 41.8 mm circle of maximum visual acuity subtended onto the face of the CRT is drawn on each density manipulation to illustrate the amount of task relevant information the circle contains.



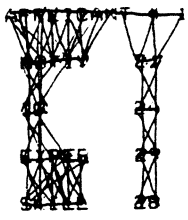
LOW OVERALL DENSITY

~~APPLICANT # 1~~		APPLICANT # 2		APPLICANT # 3		APPLICANT # 4		APPLICANT # 5	
~~MOTIV~~	~~27~~	MOTIV	21	MOTIV	26	MOTIV	27	MOTIV	27
~~IQ~~	~~23~~	IQ	20	IQ	25	IQ	22	IQ	27
~~EXPER~~	~~29~~	EXPER	27	EXPER	26	EXPER	25	EXPER	26
~~SKILL~~	~~28~~	SKILL	28	SKILL	29	SKILL	27	SKILL	20

APPLICANT # 6		APPLICANT # 7		APPLICANT # 8		APPLICANT # 9		APPLICANT # 10	
MOTIV	28	MOTIV	22	MOTIV	22	MOTIV	24	MOTIV	28
IQ	21	IQ	24	IQ	27	IQ	27	IQ	25
EXPER	25	EXPER	19	EXPER	26	EXPER	25	EXPER	22
SKILL	27	SKILL	25	SKILL	27	SKILL	25	SKILL	24

APPLICANT # 11		APPLICANT # 12		APPLICANT # 13		APPLICANT # 14		APPLICANT # 15	
MOTIV	26	MOTIV	23	MOTIV	26	MOTIV	25	MOTIV	23
IQ	23	IQ	25	IQ	22	IQ	24	IQ	23
EXPER	23	EXPER	27	EXPER	23	EXPER	26	EXPER	27
SKILL	21	SKILL	20	SKILL	20	SKILL	22	SKILL	24

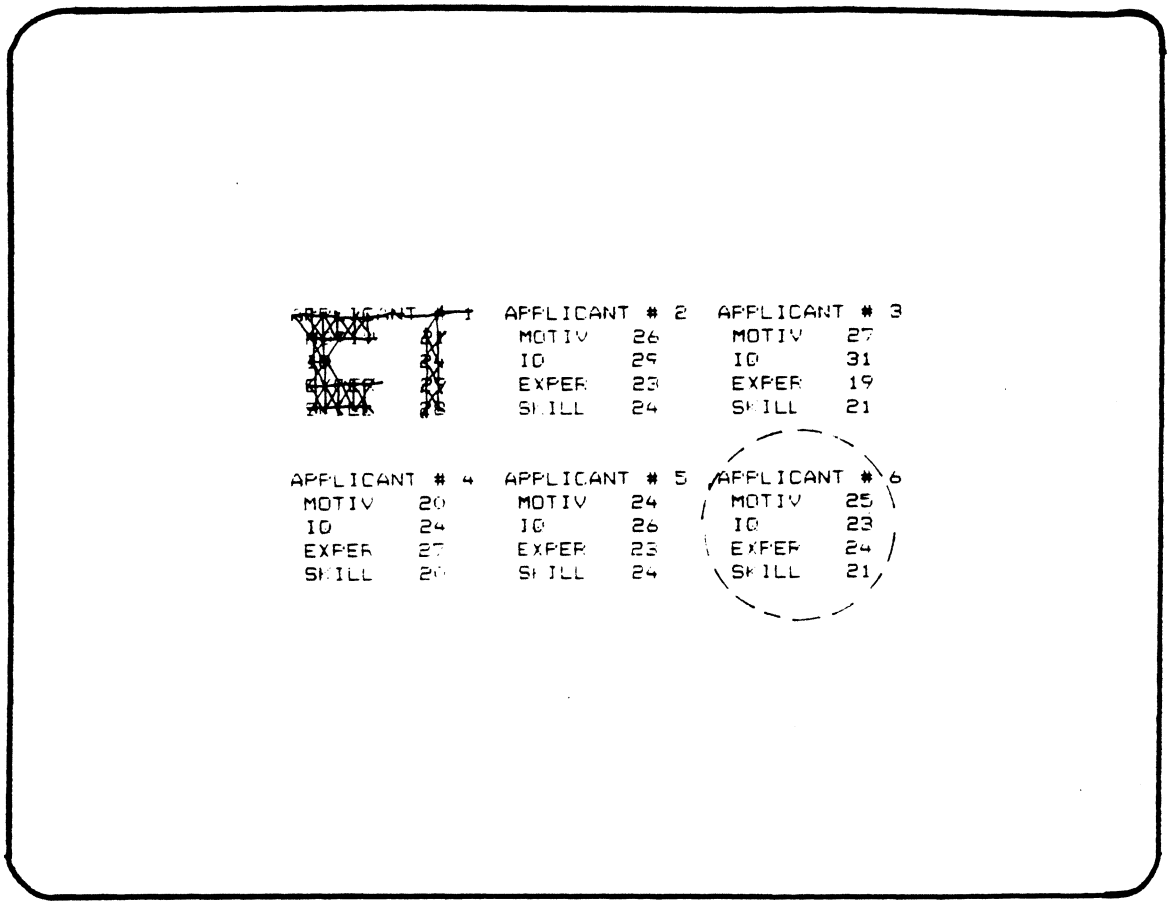
HIGH OVERALL DENSITY



APPLICANT # 1		APPLICANT # 2		APPLICANT # 3	
MOTIV	27	MOTIV	26	MOTIV	27
IQ	24	IQ	29	IQ	31
EXPER	29	EXPER	23	EXPER	19
SKILL	28	SKILL	24	SKILL	21

APPLICANT # 4		APPLICANT # 5		APPLICANT # 6	
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

LOW LOCAL DENSITY

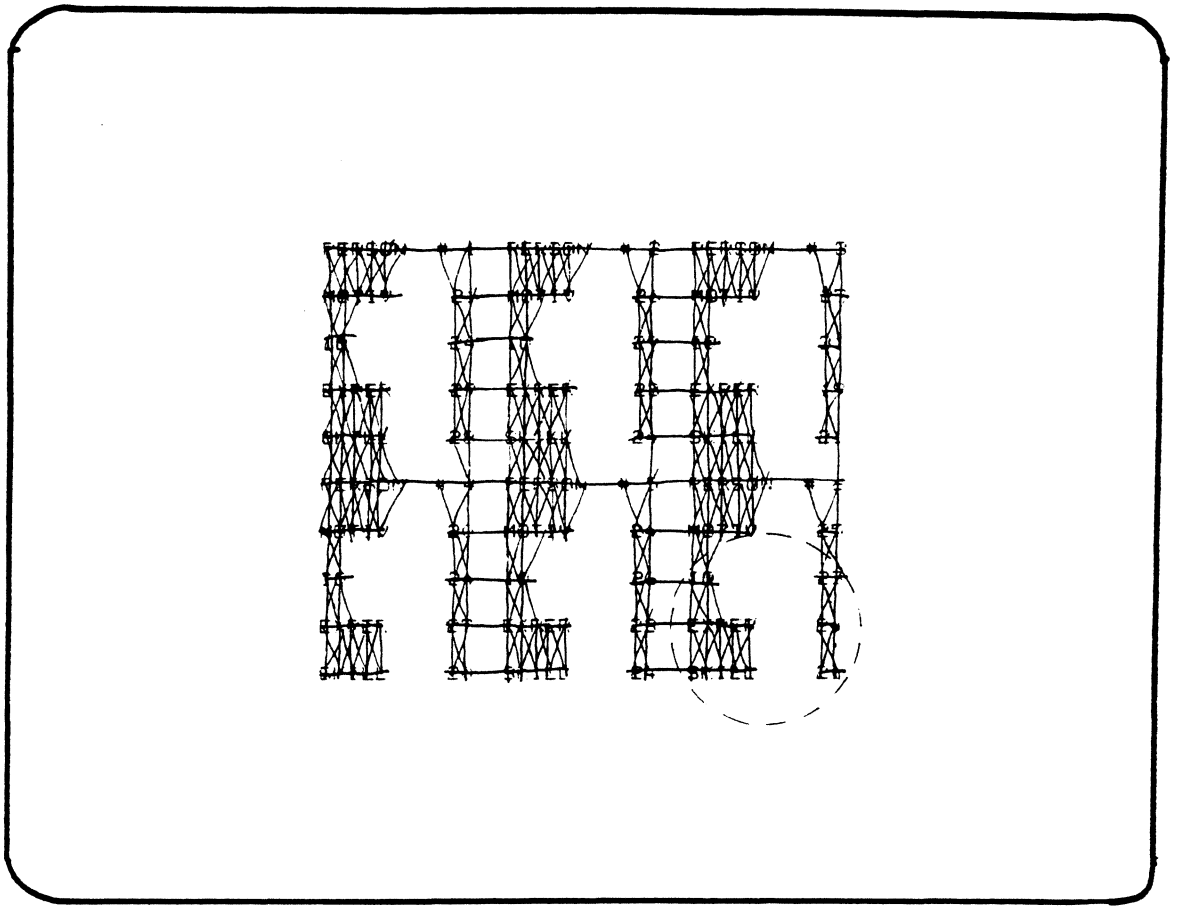


HIGH LOCAL DENSITY

PERSON	# 2	PERSON	# 3
MOTIV	26	MOTIV	27
IQ	29	IQ	31
EXPER	23	EXPER	19
SKILL	24	SKILL	21

PERSON	# 4	PERSON	# 5	PERSON	# 6
MOTIV	20	MOTIV	24	MOTIV	25
IQ	24	IQ	26	IQ	23
EXPER	27	EXPER	23	EXPER	24
SKILL	20	SKILL	24	SKILL	21

GROUPED



UNGROUPED

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