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The role of transparency in perceptual grouping and pattern recognition

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Abstract. The shortest stimulus exposure time for which transparency can be seen was examined. In the first experiment, overlapping digits were presented for 120 ms and the luminance in the overlapping regions was varied. Subjects reported, in separate blocks of trials, either the apparent transparency of the digits or the identity of the digits. When the luminance was set so that one set of digits appeared to be seen through the other, recognition of the digits was high. When the luminance in the overlapping regions did not produce impressions of transparency, digit recognition was low. In the second experiment, digit identification at several stimulus durations was compared between stimuli that had luminance that was valid for transparency and stimuli that had invalid luminance. Performance was found to be higher in the valid luminance condition than in the invalid condition after as little as 60 ms exposure duration. This result suggests that the impression of transparency requires only relatively short exposure durations.

1 Introduction

When two surfaces overlap, they produce a third region which can be seen either as a new and separate region (figure 1a) or as a region which belongs to both surfaces (figure 1b). In the second case, one surface is seen in front of the other as a transparent sheet. This phenomenon is called subjective transparency (eg Beck et al 1984; Metelli 1974; Morinaga et al 1962; Nakayama and Shimojo 1990; Oyama and Nakahara 1960; Ramachandran 1990; Watanabe et al 1992), and it indicates the ability of the visual system to code a single point on the retinal image as having more than one surface quality, in particular, two depths (near and far surfaces). Beck et al (1984) and Metelli (1974) have shown that observers report an impression of overlapping transparent surfaces in a flat image like figure 1b as long as the light values in the image conform to the following constraints derived from those of a physically transparent situation: (1) "the overlying of a transparent surface cannot change the order of the lightness values", and (2) "the lightness difference within the transparent area must be less than the lightness difference outside of the transparent area" (Beck 1986, page 6).

The purpose of our study is to determine the exposure duration necessary for the perception of transparency. In order to do so, we shall first validate a modification of a procedure for measuring transparency that was first proposed by de Weert (1986).

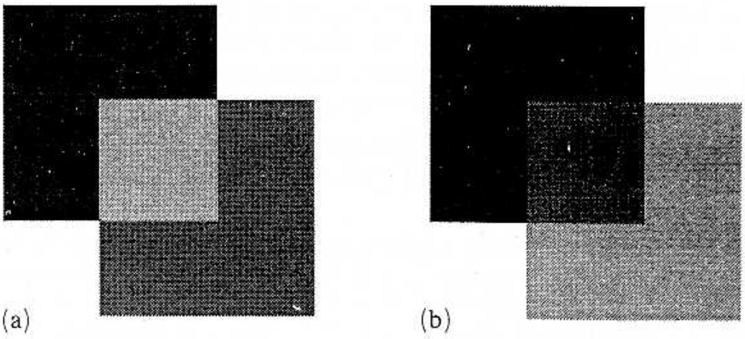

(a) (b)

Figure 1. Stimuli in which the luminance combination is (a) not valid for transparency and (b) valid for transparency.

As an objective measure of transparency, de Weert (1986) developed a pattern identification task whose results can be interpreted as a measure of functional transparency. He presented two overlapping five-letter words for 1.5 s, and observers were required to name both of them. He assumed that if transparency occurred, the regions of the stimuli could be appropriately grouped and the words more easily identified. If transparency did not occur, the stimuli appeared to be a jumble of bits and pieces and were difficult to identify. He found that when the overlapping words were presented in different colors, the error rate in identifying the words was lowest when the color in the overlapping regions was the additive mixture of the colors of the two words.

However, de Weert did not verify whether subjective reports of transparency were related to performance in the task. In addition, the words presented in his study provided many contextual cues that could have aided guessing based on visible fragments even when whole words could not be seen. Thus, in our experiments we use digits rather than words and validate the recognition performance by comparing it with subjective reports of transparency.

2 Experiment 1

In experiment 1 we examine whether the pattern identification task can be an objective measurement of the perception of transparency by comparing performance in the task with subjective judgements of transparency for exposures which would be long enough for transparency to be seen.

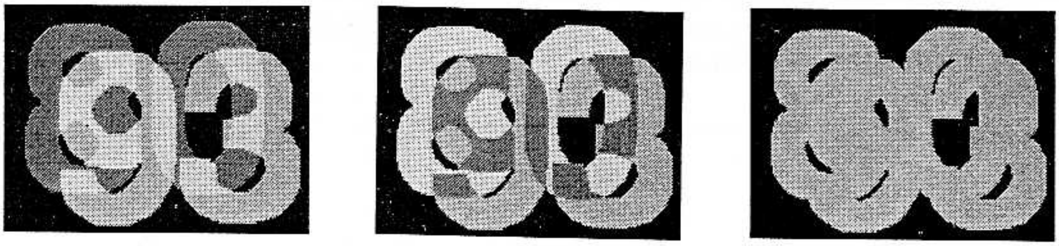
2.1 *Method*

2.1.1 *Subjects.* One man and four women, ranging in age from 26 to 32 years old, participated as subjects. All had normal or corrected-to-normal visual acuity. One of them was aware of the purpose of the experiment and the others were not.

2.1.2 *Materials.* The stimuli were presented on a color video display (Apple M0401, 640×480 pixel resolution, 66 Hz frame rate) controlled by a Macintosh IIcx and were viewed at a distance of 57.3 cm from the subject's eyes. No fixation point was presented. As a test stimulus, four digits randomly selected (with replacement) from a set of eight were presented simultaneously, as shown in figure 2. Luminance of the digits was varied to give three conditions: a valid luminance condition; an invalid luminance condition; and a silhouette condition. In the valid luminance condition, the luminances of the overlapping area, the remaining parts of the upper digits, and those of the lower digits were 30, 22, and 26 cd m^{-2}, respectively. This luminance combination is valid for the two transparency constraints mentioned in section 1. In the invalid luminance condition, these same areas had luminances of 22, 30, and 26 cd m^{-2}, respectively. This combination violates the first constraint according to which the overlying of a transparent surface cannot change the order of the lightness values. In the silhouette condition, the luminance of all these areas was 26 cd m^{-2}. The background luminance in each of the three conditions was 17 cd m^{-2}. The average Michelson luminance contrast between the overlapping areas and the remaining parts of the upper and lower digits were 11%, 12%, and 0% in the valid, invalid, and silhouette conditions, respectively. The average luminance contrasts between the digits and the background were 17%, 21%, and 24% in the three conditions, respectively.[1]

[1] In pilot experiments, we found that the performance was affected not only by the presence or absence of transparency but was also quite strongly affected by the luminance contrast between the overlapping and nonoverlapping regions of the digits and between the digits and the background. Therefore, we attempted to maintain similar contrasts in valid and invalid luminance conditions. In the silhouette condition there was, by definition, no contrast between the overlapping and nonoverlapping regions.

The width and height of the digits subtended 4 and 6 deg in visual angle, respectively. The stroke width was 1 deg. The horizontal and vertical outer dimensions of the whole set of overlapping digits were 9.5 and 7 deg, respectively. The mask consisted of 300 (20×15) black (0.5 cd m^{-2}) and white (118 cd m^{-2}) squares whose locations were randomly arranged. The squares were 1 deg on each side.



(a) (b) (c)

Figure 2. Examples of stimuli used in (a) the valid luminance condition, (b) the invalid luminance condition, and (c) the silhouette condition of experiment 1. The luminances of the stimuli shown here are representative of those used in the stimuli but do not reproduce them exactly.

2.1.3 *Procedure.* Experiment 1 consisted of two blocks: the pattern identification task, and the rating task for the degree of transparency. In each trial of the pattern identification task, 1 s after a brief tone, the test stimuli were presented for 120 ms and were followed immediately by the mask, presented for 1 s. Following the onset of the mask, a uniform gray field was presented for 1 s. The eight digits from which the four presented digits had been chosen were then presented side by side in the upper part of the display. The subjects used a mouse device to position a cursor over the digits that they judged had been presented in the test stimulus, and pressed a button on the mouse. As soon as subjects had indicated four digits, the eight digits disappeared and the next trial started. There was no feedback about the accuracy of the responses. A total of 120 trials were presented in a random order. Forty combinations of four digits were randomly chosen for each of the three conditions; valid luminance condition, invalid luminance condition, and silhouette condition.

In the second task, subjects were first shown several patterns, half of which simulated physical transparency and half of which did not, in order to establish their criterion in the subjective rating of transparency: 0 meant no transparency, and 10 indicated a very high degree of transparency. The subjects were then presented with the same stimuli as in the pattern identification task and were asked to rate the degree of transparency of the two digits through which the other two were seen. Following the presentation of the test and the mask, they had to click on the number they chose as a rating. Twenty combinations of four digits, randomly chosen, were presented in each of the three conditions in a random order for a total of 60 trials. Otherwise, the experimental procedure was identical to that for the pattern identification task. For each subject, the pattern identification task was run first, followed by the rating task.

2.2 *Results*

In figure 3, the mean value in the rating task and the mean percentage of correct responses in the pattern identification task are plotted for each of the three luminance conditions. Data in the pattern identification task were subjected to one-way analysis of variance after arc sin transformation. The main effect of luminance condition was significant ($F_{2,8} = 85.63$, $p < 0.0001$). A posteriori pairwise comparisons (Newman-Keuls) showed that the mean percentage of correct response in the valid luminance condition was significantly higher than that in the invalid luminance condition ($p < 0.01$) and than that in the silhouette condition ($p < 0.01$). The mean percentage of correct responses in the invalid luminance condition was also significantly higher than that in the silhouette condition ($p < 0.01$). Data in the rating task were subjected to one-way analysis of variance. The main effect of luminance condition was again significant ($F_{2,8} = 103.48$, $p < 0.0001$). The a posteriori pairwise comparisons showed that the mean percentage of correct responses in the valid luminance condition was significantly higher than that in the invalid luminance condition ($p < 0.01$) and than that in the silhouette condition ($p < 0.01$). The latter two were both nearly 0%. These results of the rating task indicate that transparency was seen only in the valid luminance condition.

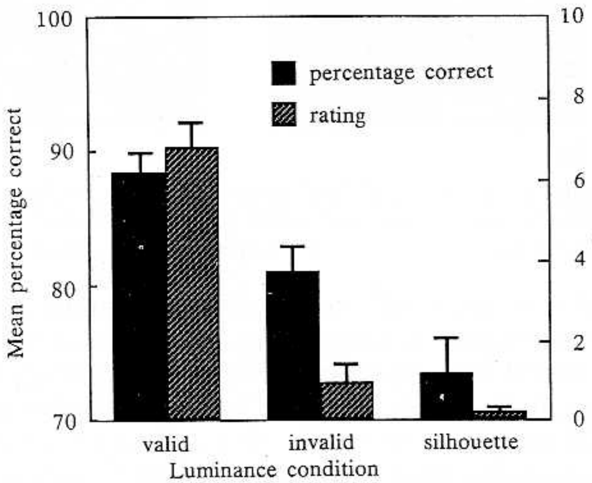


Figure 3. The mean percentage correct responses and the mean values in the rating task in experiment 1 are plotted for the valid luminance, the invalid luminance, and silhouette conditions. Vertical bars represent standard errors.

2.3 *Discussion*

These results suggest that high performance in the pattern identification task was accompanied by high ratings of transparency. The significantly higher percentage of correct responses in the valid condition indicates that the digits were more easily identified in this condition. We suggest this advantage derives from the transparency of the overlying digits, a percept which allows the upper and lower digits to be perceived as whole digits as opposed to fragments. The percentages of the correct responses for the invalid and the silhouette conditions are greater than chance levels of 12.5%. This may be because some digits are still identifiable from their local features in the invalid luminance and in the silhouette conditions. The reason for the significantly higher percentage of correct responses in the invalid condition than in silhouette condition may be that the completeness of the outlines of all digits in the invalid luminance condition gave more local information than in the silhouette condition.

3 Experiment 2

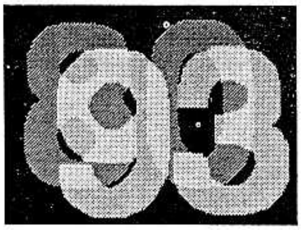
We used the pattern identification task to examine the minimum stimulus duration required for the perception of transparency. We also introduced the condition that the digits did not overlap, so as to determine the upper limit on performance for digits presented separately.

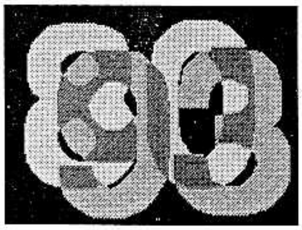
3.1 *Method*

3.1.1 *Subjects.* Three men and two women, ranging in age from 26 to 32 years old, participated as subjects. All of them had normal or corrected-to-normal acuity. With the exception of one who had participated in the first experiment, all were naive as to the purpose of this second experiment.

3.1.2 *Material.* As shown in figure 4, there were four stimulus conditions; (a) valid luminance and overlapping digits, (b) invalid luminance and overlapping digits, (c) 'valid' luminance and separate digits, and (d) 'invalid' luminance and separate digits. The luminance combinations in the valid and invalid luminance conditions were identical to those in experiment 1. The layout of digits in the overlapping-digits conditions was identical to that in experiment 1. The digits in the separate-digits conditions were presented with no spatial overlap. In the 'valid' luminance condition, the luminance in the upper two digits was 22 cd m^{-2} and that in the lower two digits was 26 cd m^{-2}, the same values as for the valid overlapping condition except that there was no overlapping region. In the 'invalid' luminance condition, the luminance in the upper two digits was 30 cd m^{-2} and that in the lower two digits was 26 cd m^{-2}, the same values as those in the invalid overlapping condition.

3.1.3 *Procedure.* In each trial, the test stimulus duration was randomly chosen to be 30, 60, 90, 120, or 150 ms. Ten combinations of four digits, randomly chosen (with replacement) out of the eight, were presented for each of the five durations in each of the four conditions, in a random order, for a total of 200 trials. Otherwise, the experimental procedure was identical to that of experiment 1.


(a)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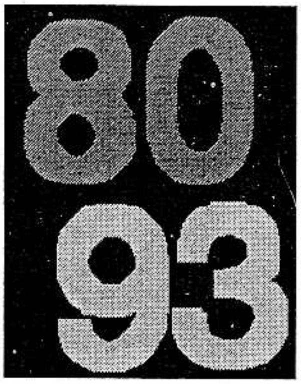
(c)

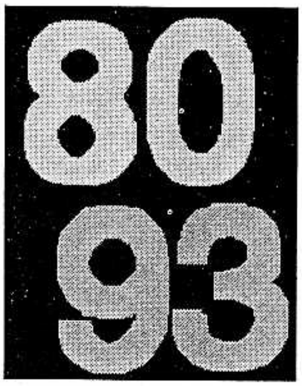
(d)

Figure 4. Examples of the stimuli used in (a) the valid luminance and overlapping-digits condition, (b) the invalid luminance and overlapping-digits condition, (c) the 'valid' luminance and separate-digits condition, and (d) the 'invalid' luminance and separate-digits condition of experiment 2.

3.2 *Results and discussion*

In figure 5, the mean percentages of correct responses in the four conditions are plotted as a function of duration. The percentages of correct responses in the separate-digits conditions did not vary as a function of the luminance ('valid' or 'invalid') and so are combined in the graph. In the overlapping conditions, with more than 30 ms durations, the percentages of correct responses are higher in the valid luminance condition than those in the invalid luminance condition.

From these results we may say that the performance advantage seen to accompany the perception of transparency in experiment 1 occurs for stimulus presentation as short as 60 ms.

It is notable that even for a duration of 150 ms, the percentage of correct responses in the valid luminance and overlapping-digits condition is still lower than in the conditions with separate digits. This suggests that perceptual separation of the digits is not perfect even if the digits are seen as being transparent.

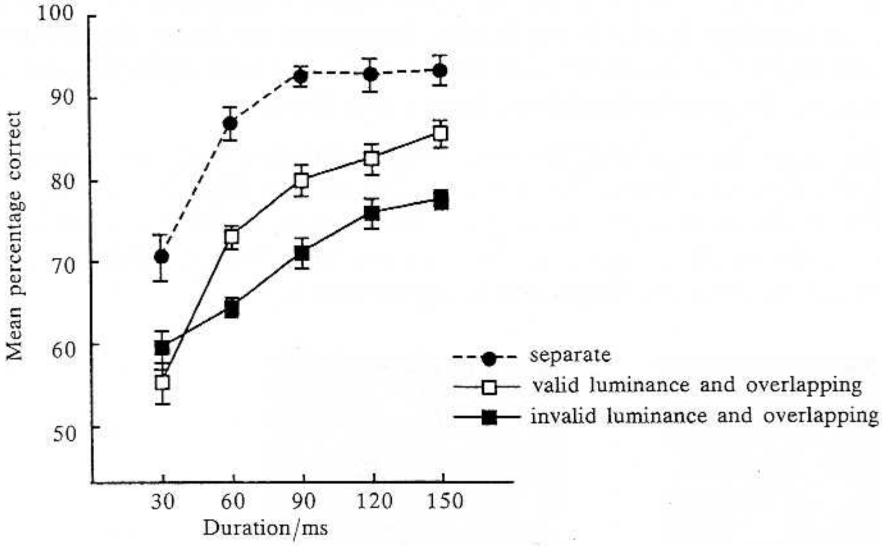

Figure 5. The mean percentages of correct responses in experiment 2 in (a) the separate-digits condition, (b) the valid overlapping condition, and (c) the invalid overlapping condition are plotted as a function of duration. Vertical bars represent standard errors.

4 General discussion

In the present study, we found that subjective transparency occurs even at the stimulus exposure of 60 ms. More precisely, we found that the performance advantage that accompanies reports of subjective transparency occurred for exposures as short as 60 ms. We believe that the subjective impression of transparency and the accurate identification performance are both the result of the same phenomenon—the grouping of the stimulus patterns into whole digit forms. Surprisingly, the 60 ms duration is shorter than the durations at which illusory contours (Reynolds 1981), and the Ponzo, Zöllner, and rod-and-frame illusions (Reynolds 1978) become visible. This suggests that subjective transparency is accomplished very rapidly and rather automatically. This rapid processing for transparency might be related to the ecological importance of rapidly distinguishing opaque objects from transparent ones, such as fish from water.

Some researchers suggest that the duration required for the perception of a phenomenon is related to the locus of its perceptual genesis and that the shorter the duration or interstimulus interval, the earlier it occurs in the sequence of processing stages (Epstein et al 1977; Gellatly and Bishop 1987; Reynolds 1978, 1981). If this assumption is correct, our results might suggest that the locus of at least a part of the grouping processes that accompany transparency perception is comparable to the loci of the above-mentioned effects.

In his original pattern identification task, de Weert (1986) used overlapping pairs of words. In the present study, we showed that even randomly chosen digits can be used for this task. This modification made the task much simpler and reduced the probability of guessing words from letter fragment. If geometric figures instead of digits are used, this task could be appropriate for populations able to perform recognition tasks but unable to follow more complicated subjective instruction such as "whether one pattern is seen through the other".

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