Validating the Effectiveness of Recursive Blur Enhancement of Symbol Signs using Static and Dynamic Protocols

Robert McCall and Frank Schieber
Heimstra Human Factors Laboratories
University of South Dakota
Vermillion, SD 57069

Previous laboratory research has demonstrated that symbolic highway signs which have undergone the Recursive Blur Technique of visual enhancement exhibit significantly increased legibility distances over standard symbolic highway signs when using a *critical detail identification* task. This study sought to extend those findings to a new stimulus subset, and develop an identification task that is more conducive to a real-time (dynamic) driving environment. The effects of recursive blur enhancement on legibility distances were replicated using the critical detail identification task for both existing and novel stimuli, but the new holistic identification protocol proved to be an insensitive measure of the effect. Future research on this topic must be able to meet the temporal constraints posed by a dynamic driving environment without sacrificing the sensitivity of a detail-oriented identification protocol.

It has long been known that symbolic highway signs yield significantly longer legibility distances compared to their text-based counterparts (Jacobs, Johnston, & Cole, 1975, Dewar and Ells, 1974, Ells and Dewar, 1979). Furthermore, these improvements in legibility distance extend over a wide range of deleterious conditions such as fog and rain (Ells and Dewar, 1979). One of the explanatory mechanisms behind this finding is the strong correlation between an object's spatial frequency composition and its legibility distance (Schieber, 1994). Knowing that spatial frequency content and legibility distance are intertwined gives researchers the ability to exploit that relationship in an attempt to increase the legibility distance of both existing and newly designed highway sign symbols. This is done through the use of a method known as the recursive blur technique.

Simply put, the recursive blur technique (RBT) is a process by which an image, in this case a sign symbol, is blurred until some critical details are no longer recognizable. Those details can then be enhanced by a graphic designer. Typically, such modifications include enlarging certain features, increasing the distance between the symbol and the border, or increasing the separation of nearby features. In order to perform the recursive blur technique one of two blurring methods can be employed. The optical method uses spherical lenses to systematically blur the image, while the digital method of blurring uses Fourier-domain filters to more predictably and precisely accomplish the same goal. This involves the use of a low-pass filter to attenuate the high spatial frequency information. The remaining mid to low spatial frequency information presents itself as a blurred image. The digital method of RBT blurring allows researchers to measure the spatial frequency composition of a stimulus sign in an exact and controlled manner thereby removing a portion of the subjectivity inherent in the method.

Once the image has been blurred the designer and/or experimenter takes note of what details require attention, and deblurs the image while those enhancements are made. Upon completion of the corrections/enhancement procedure for a particular cutoff frequency the image is once again blurred, but this time to a higher degree. Once again the artist/experimenter uses their expert opinion to deblur and make corrections to the image. This process continues recursively until no further improvements can be achieved. The finished product is then shown to participants in a state of zero blur.

Kline and Fuchs (1993) were the first to examine the effects of the recursive blur technique on highway sign legibility distances. Using the optical blurring method they tested text, symbol, and enhanced symbol signs across three age groups (young, middle-aged, and old). In order to simulate a dynamic visual environment one encounters while driving Kline and Fuchs increased the size of the sign by 7% of its size on the previous trial if a predetermined list of criteria set forth for correct identification were not satisfied. The stimulus size at which all criteria were reported was then used to define each sign's scaled legibility distance. This method of identification is henceforth referred to as the *critical detail identification protocol.*

The overall size at which symbol signs became legible was approximately half the size of their text-based counterparts. This finding is consistent with the overall superiority of symbol signs which had been previously established by Ells and Dewar (1979), and supported by numerous other authors. Furthermore, Kline and Fuchs (1993) found that the RBT-enhanced symbol signs had a legibility distance roughly twice that of the standard symbol signs for older and middle-aged drivers, and younger drivers noticed an increase by one-third over the legibility distance of standard symbol signs.

In 1997 the U.S. Federal Highway Department issued the *Symbol Signing for Older Drivers* report. In this work the recursive blur technique once again proved to be a valuable tool for increasing the legibility distance of highway sign symbols. For the purpose of the FHWA report three studies of the performance gains associated with the recursive blur technique were performed. Across three age groups (young, middle-aged, and older) novel, existing, and RBT-enhanced road signs were examined in simulated daytime, nighttime and nighttime with glare viewing conditions. It was found using the *critical detail identification* task that for all three experiments stimuli which underwent the recursive blur technique of enhancement demonstrated increased legibility distances over both the novel and redesigned road signs, with the elderly age group demonstrating the greatest gains overall. The findings that older drivers demonstrate the greatest advantage when the recursive blur technique is employed can be partially explained by the reductions in the ability to detect medium and high spatial frequency targets which accompanies the normal aging process (Schieber et al., 1992). Since the RBT limits the amount of high spatial frequency information present on a stimulus sign these results were to be expected.

The present study sought to validate the performance improvements associated with the recursive blur technique in a real world driving context. Currently the benefits of RBT enhancement have only been demonstrated within the narrow confines of the laboratory due to several challenges needing to be overcome prior to a real-world validation process. Unfortunately, the *critical detail identification* protocol used in all prior studies requires more time to complete a response than what is available in the dynamic driving environment. In order to overcome this obstacle a new protocol was developed. The *holistic identification protocol* requires the participants to name the whole object depicted on each stimulus sign rather than separately describing each sub-component or feature. This modification of the protocol permits real-time estimates of legibility distance in the case observations made from a moving vehicle.

The adoption of a new protocol that was compatible with the real time constraints of driving, however, introduced several potential interpretational difficulties. If the results obtained under real-world driving conditions failed to replicate previous laboratory findings it would be impossible to know whether this outcome was due to differences across settings (laboratory versus road) or differences in the sensitivities of the assessment protocols (critical detail versus holistic identification).

One approach to dealing with these potential interpretational difficulties was to conduct a laboratory experiment that directly segregated the competing explanatory mechanisms. Such a study would need to evaluate the effects of at least two factors upon the performance benefits afforded by RBT enhancement. One factor would need to contrast the two protocols used to assess legibility distance. Another factor would need to contrast visibility levels obtained with control versus RBT-enhanced symbol signs. Careful consideration suggested that still a third factor needed to be evaluated in the laboratory study. This factor was related to the inspection time available to the participants across the two assessment protocols described above. In the case of the *critical detail identification protocol*, participants are provided with an unlimited amount of time to view each stimulus prior to making a response. This occurs because the size/distance of the stimulus sign remains unchanged no matter how long the participant takes to respond. This independence of inspection time and stimulus size/distance can no longer be maintained in the case of the dynamic driving environment in which the *holistic identification protocol* was to be used. In order to evaluate the potential influence of inspection time, *per se* upon performance it was necessary to directly manipulate the levels of this variable. Therefore the proposed laboratory experiment would also contrast unlimited inspection time to situations where only a brief glance was available. The duration of the brief glance condition was set at 600 msecs since this is representative of typical highway sign fixation times observed by drivers in real-world settings (Green, 2002; Zwahlen & Schnell, 1998). The stimuli used in this study are pictured below (Figure 1). Novel stimuli are pictured on the left, and those used by Kline and Fuchs to the right.

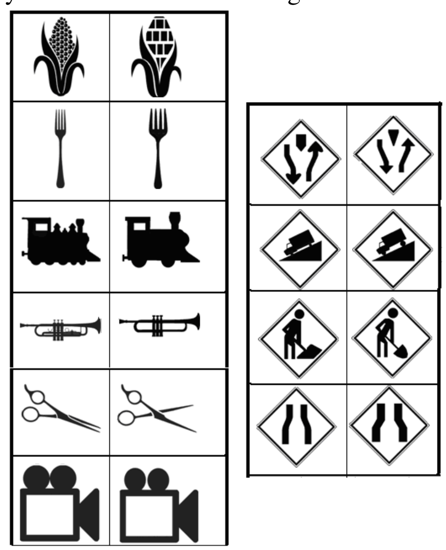

Figure 1. Proposed stimuli with pre optimized on the left, and their optimized counterparts to the right. Figure on the right are the pre and post optimized stimuli used by Kline and Fuchs, 1993.

The rational for using non-regulation stimuli in conjunction with the regulation highway signs used by Kline and Fuchs (1993), was that by placing actual signs on the roadway, experimenters could potentially misinform motorists of possible changes in road conditions ahead. In an attempt to avoid such possibilities this study planned to use non-regulatory signs to assess these experimental manipulation on legibility distances.

Methods

Participants.: Ninety-six (8x12) undergraduate students from the University of South Dakota were recruited to participate in this experiment (68 female). The participants ranged in age from 18 – 35 years old. All subjects demonstrated normal or corrected to normal visual acuity of 20/25 or better with no self reported visual abnormalities.

Apparatus Visual acuity of each participant was tested with a Bausch and Lomb Orthorater using binocular, far vision plates. The Kline and Fuchs (1993) MUTCD and enhanced MUTCD images were used with permission. Novel (non MUTCD) stimuli were purchased from www.istockphoto.com. They were then blurred, and presented using a Windows 2000 computer running Matlab version 7.1 with the Cogent 2000 add-on, and the Image Processing Tool-kit. Enhancement was performed using Adobe Photoshop version 7.0, and stimuli were presented on a color CRT monitor with a native resolution of 1280 x 1024 at a distance of 7.6 meters (25 feet) from the seated participants.

Procedure Upon reading and signing a document of informed consent participants were randomly assigned to one of eight experimental conditions. Following a briefing of their task they were given four practice stimuli in order to gain familiarization with the process. Practice stimuli were presented in the same manner as the participant's experimental condition. That is, the images were either enhanced or non-enhanced, presented for either brief or unlimited viewing times, and the participants were to employ either the holistic or critical detail identification protocols as dictated by their condition and explained by the experimenter.

If a person was to perform the holistic identification task, they were instructed to report the name of the object that was being depicted on the computer monitor. An example of the holistic identification task would be: if the picture being displayed was of a tennis racket then the participant simply had to say "tennis racket" for the stimulus to be considered legible. The stimulus size at which the participant could correctly identify the object was recorded as the threshold size for that participant. If the participant could not correctly identify the object, the size of the object was increased by 7% of its size on the previous trial. Stimulus size was increased systematically until the target name was correctly specified.

If the participant was in one of the conditions to perform the critical detail identification task, the stimulus object would not be deemed legible until that participant could identify all of the visual information in a predetermined list of criteria defining the stimulus. For instance, that list may include such features as "handle," or "strings" in the tennis racket example used above. If the participant could not identify all of the "critical details" then the size of the image was increased by 7% of its size on the previous trial. This continued until all necessary critical detail requirements were met.

In the static inspection time condition, participants were given unlimited time to inform the experimenter as to what it was that they saw on the monitor. Depending on their identification task (holistic versus critical detail), the instructions varied as to what they had to report. In the brief glance inspection time condition the stimulus appeared for a brief (600 msec) exposure at each size with a fixation box the same size and location of the upcoming image for a period of three seconds. Once the stimulus sign met the requirements of legibility the threshold size was recorded and the next image was presented until all ten threshold sizes had been recorded.

Results

The first analysis of the data addressed the issue of replication of previous findings demonstrating the efficacy of the RBT enhancement technique. A 2 (sign type: enhanced vs. nonenhanced) by 11 (individual stimulus signs: four from Kline & Fuchs; seven novel symbols) ANOVA was performed upon the legibility data collected using the *critical detail protocol* under unlimited viewing time conditions. There was a significant main effect of sign type, [$F(1,22) = 13.366$, MSE = 2.647, $p = 0.001$, $\eta^2 = 0.378$] as well as a significant effect across individual stimulus signs [Greenhouse-Geisser F (4.369, 96.112) = 21.860, MSE = 58.271, $p < 0.0001$, $\eta^2=0.455$] . Furthermore, the interaction between sign type and individual signs proved to be significant, [Greenhouse-Geisser F (10.96, 22) = 4.048, MSE = 0.0842, $p = .003$, $\eta^2 = 0.155$]. The nature of these effects is depicted in Figure 2. Overall, RBT-enhanced signs could be recognized at smaller threshold sizes than their nonenhanced counterparts. This effect was observed for Kline & Fuchs original stimuli as well as our novel symbol subset.

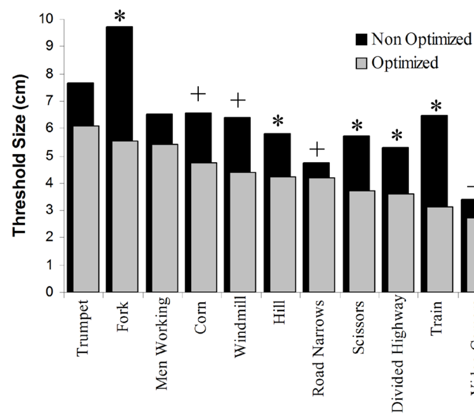

Figure 2. Interaction between individual sign (x-axis) and sign type (black and gray bars) in the unlimited viewing time, critical detail identification task condition. * denotes $p <= 0.01$, + denotes $p <= 0.025$.

The second group of analyses examined whether the same pattern of RBT-enhancement effects could be observed using the real-time *holistic identification protocol* (a necessary condition prior to beginning on-road research). Again, a 2 (sign type) by 11 (individual stimulus signs) ANOVA was conducted upon the legibility data collected under the unlimited inspection time conditions. Neither the main effect of sign type (enhanced versus nonenhanced) [F (1, 22) = 1.092, $p > 0.30$, MSE = 1.592] nor its interaction across individual stimulus signs [Greenhouse-Geisser F (5.412, 44.733) = 2.037, $p = 0.07$, MSE = 0.376] yielded statistically reliable outcomes. There was a significant main effect of individual stimulus signs [Greenhouse-Geisser F (5.412, 44.733) = 11.569, $p < 0.0001$, $\eta^2 = 0.325$, MSE = 0.376]. Unlike the case for the critical detail approach, the *holistic identification protocol* proved to be insensitive to the effects of the RBT enhancement procedure.

As noted above, this study also examined legibility performance under brief (600 msec) as well as unlimited inspection durations. The failure to demonstrate the efficacy of the *holistic identification protocol* essentially eliminated the need for this experimental manipulation. Nonetheless, the analyses described above were repeated for this subset of data. The pattern of results obtained for the 600 msec condition was virtually identical to that reported for the unlimited inspection time condition. Given space limitations and the moot status of the *holistic identification protocol* the details of these analyses have been omitted.

Discussion

The first finding of interest is that the current investigators were able to once again demonstrate the efficacy of the recursive blur technique when using the *critical detail identification task* on the same highway sign stimuli which were used by Kline and Fuchs (1993). In addition, the effects of recursive blur technique (RBT) enhancement were realized in a new subset of stimulus symbols. This extension shows that the effects of RBT enhancement are not limited to any particular subsets of images. Furthermore, the new stimuli were able to realize the improvements in legibility distance when using a digital (as opposed to optical) blurring method. This gives practitioners a blurring technique which is both predictable and easily communicated from one laboratory to another by simply reporting the Fourier-domain cutoff frequencies used in the blurring procedure.

However, there were some issues with our development and ultimately the implementation of the *holistic identification protocol*. The aim of this laboratory examination was to develop an experimental identification task which would allow for accurate and precise measures of legibility distances in a dynamic driving environment. While the *critical detail identification protocol* has once again proven to be a sensitive measure in capturing the effects of RBT enhancement, a technique with higher temporal resolution is needed for testing on the roadway. The *holistic identification protocol*, while exhibiting high temporal resolution, lacked the necessary sensitivity to reliably capture the effect.

Informal observations of participant behavior while performing the experimental tasks may provide some basis for speculation regarding the insensitivity of the *holistic identification protocol*. While running participants, the experimenter [RM] noticed that subjects using the *critical detail identification protocol* tended not to generate hypotheses regarding the overall meaning of the symbol signs when the size of the stimulus was still too small to afford successful recognition. Instead, they focused upon the analysis and report of subfeatures as they emerged from the “fog” of simulated distance rather than formulate “wild guesses” about the global identity of the stimulus form. On the contrary, participants assigned to the *holistic identification protocol* demonstrated a strong tendency to formulate false hypotheses regarding the identity of the global form long before the stimuli reached threshold size. Once more, these false hypotheses appeared to exhibit what can be described as cognitive inertia. That is, once formulated they required substantial stimulus evidence to overcome. Entertaining a false hypothesis appeared to interfere with the formulation of new, potentially correct, identifications. Once correct identification was made several participants claimed that they could see the details of the stimulus object prior to the determined threshold level, but were unable to dismiss the initial identification of that object even when given evidence to the contrary by the experimenter. The haphazard formation of such “garden path” hypotheses may have contributed significantly to the reduced sensitivity of the *holistic identification protocol*.

Future research on the effects of RBT enhancement should focus on employing an identification technique which directly compares the legibility distance of enhanced and nonenhanced stimulus signs in a dynamic environment while mitigating the role of hypothesis testing strategies observed in some participants of the current study. One technique for doing just that would be to use a two-alternative forced choice paradigm which puts RBT enhanced and nonenhanced stimulus signs in direct competition. In this scenario two signs would be placed within close proximity of one another. One will have undergone the recursive blur technique and the other not. As the vehicle approaches the two stimulus signs the participant would be tasked with correctly identifying the first one which becomes legible. If the sign which has undergone RBT is the first to be identified by a statistically significant margin it could be safely stated that RBT enhancement provides a measurable increase in the legibility distance of symbolic highway signs. This lab intends to make attempts to develop such a testing protocol, and hopes to have reportable results from the roadway by the next meeting.

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