An Evaluation of Information Visualization in Attention-Limited Environments

Jacob Somervell, D. Scott McCrickard, Chris North, Maulik Shukla
Department of Computer Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0106 USA
jsomerv@vt.edu, mccricks@cs.vt.edu, north@cs.vt.edu, mshukla@vt.edu

ABSTRACT
People often need to quickly access or maintain awareness of secondary information while busy with other primary tasks. Information visualizations provide rapid, effective access to information, but are generally designed to be examined by users as the primary focus of their attention. The goal of this research is to discover how to design information visualizations intended for the periphery and to understand how quickly and effectively people can interpret information visualizations while they are busily performing other tasks. We evaluated how several factors of a visualization (visual density, presence time, and secondary task type) impact people’s abilities to continue with a primary task and to complete secondary tasks related to the visualization. Our results suggest that, with relaxed time pressure, reduced visual information density and a single well-defined secondary task, people can effectively interpret visualizations with minimal distraction to their primary task.

Keywords: Information visualization, information density, dual-task situations, empirical evaluation, peripheral displays

INTRODUCTION
People need information. Many decisions and actions are based on information gathered from a variety of sources. The weather dictates what people wear and whether they carry umbrellas. Stock prices influence investments. Traffic information helps decide which routes to take and which not to take. With the advent of the internet and wireless technology, these and other information are readily available on computer desktops, cell phones, handheld computers, in-dash vehicle displays, and elsewhere.

With the availability of this information comes the problem of presenting it in an effective manner. The field of information visualization investigates methods for addressing this problem using graphical representations that capture and reflect important aspects of the information [3, 23]. Information visualizations can enable users to quickly assimilate large amounts of data, and empirical evaluation has led to improved designs over time [4]. However, the evaluation of information visualizations has focused almost exclusively on situations in which users explore the information in a visualization as their only task. In reality, using a visualization is quite often not a person’s sole or primary task. Computer users have long used visualizations such as email tools and system load monitors to keep track of information while performing other tasks. Today, as information from chat tools, Web alert systems, stock tickers, buddy lists, schedules, and other sources invade our desktops, it is important to understand how best to communicate this information in an effective manner with minimal negative impact on the user’s other tasks.

Complex information visualizations often require significant attention to analyze, and their presence can and does affect other work. This paper explores the use of information visualizations as secondary displays (peripheral visualizations). In general, a person’s attention will be focused on some primary task, but at times it may be necessary to divert partial attention to a secondary task that involves gathering information from a visualization. This may occur through peripheral vision or shifts in visual focus, but the primary focus of attention should remain on the primary task. Hence, only limited attention can be devoted to the secondary visualization task. For example, a student may want to work on a collaborative assignment while watching for chat messages from his colleagues, or an investment professional may want to monitor stock prices while sending email to her clients, or the driver of a vehicle may want to look at map directions while driving.

In order to design information visualizations intended for secondary tasks, more understanding is needed about the utility of visualization in multiple-task situations. It is suspected that such visualizations are distracting, but little is known about the degree to which it distracts users and whether users can overcome these distractions and interpret the peripheral visualizations. Similar to standalone information visualizations, we expect that peripheral visualizations will have some benefits in terms of user performance for assimilating information. However, we also expect that the design of peripheral visualizations will need to be different than that of standalone visualizations. For example, typically a goal in information visualization design is to maximize visual information density [25]. But in peripheral visualizations, increased visual density may result in additional distraction and decreased user performance.
In this research, we conduct controlled empirical evaluations that examine the impacts, both positive and negative, of the use of information visualization as a secondary task under a variety of conditions.

We attempt to address two primary questions with this work:

1. **How quickly and effectively can people interpret an information visualization while busily performing other tasks?** That is, we want to learn whether people can partially switch from their primary task to the secondary visualization task when an information visualization is presented. We examine people’s performance on the visualization tasks and the distraction on their primary task during and after the presentation of a peripheral visualization.

2. **How can peripheral visualizations be designed to reduce distraction while maintaining awareness?** For example, a visualization that contains more data points has the potential to better show clusters and trends in the data, but it seemingly becomes more difficult to quickly focus on individual data points and can cause distraction. In search of a winning combination or tradeoff analysis, we examine several attributes of information visualizations including visual information density, presence time, and task type.

In answering these questions, we hope to establish guidelines for the presentation of information visualizations in the periphery. This work represents the initial stages of a lengthy series of studies to achieve this goal. This research has the potential for long range impact in many domains. For example, studies have shown that integrated in-vehicle systems do decrease the attention of the driver to the driving task, but do communicate information more effectively than non-integrated systems [9]. Effective methods for the timing, placement, and representation of information in in-vehicle information systems could impact safety issues and help prevent serious accidents.

**RELATED WORK**

Many of the guidelines we used in defining our experiments stemmed from early research on perception in user interfaces. Some of the earliest evaluations examined the perceptibility and readability of rapid serial visual presentations (RSVPs) of letters, strings, and words [10, 14]. More recently, researchers have been examining the effectiveness of graphical displays when presented for short times, focusing on changes in visual features like color and orientation [20, 24, 6]. Others considered the effects of visual attributes such as texture, lumincence, dimensionality, and motion in the visual display [8, 12, 13]. This work required participants to quickly interpret complex visual displays, resulting in guidelines for the use of color in display design.

While perception plays a part in the understanding of information in the periphery, also important is the ability to transition attention between tasks quickly and easily. All the previously mentioned evaluations considered the viewing of displays as the sole task of the user. However, in multi-task environments, users would be balancing attention. In recent years, several research teams have examined the effects of displaying information or attracting attention to displays in the periphery while the user is attempting some primary task [2, 7, 18, 19, 22]. For these studies, the researchers conducted dual-task experiments in which participants performed some central tasks while various types of displays showed different types and amounts of information. This information was used in answering questions or performing secondary tasks. In general, the displays in the periphery were textual [7, 18, 19] or simple graphical [2, 22] displays.

Our research follows a similar experimental design, but differs in that we are focusing not on textual or simple graphical displays but on visualizations that use many factors (color, shape, position) to communicate information. As is explained in the next section, we used prior results as guidelines in identifying reasonable bounds for our experimental design.

**EXPERIMENTS**

In conducting the experiments, we examine how various factors affect the ability to assimilate information from displays in the periphery. Specifically, we focus on three factors: visual information density, visualization presence time, and the type of task the user wants to accomplish with the information.

Little work has been done to assess the various effects visual information density may have on information assimilation, particularly in multi-task situations. We speculate that the recommended density may depend on the use of the data. For example, displaying many data points may be beneficial for recognizing patterns in the data, while displaying fewer data points may be more helpful for determining a specific value or datum. If one is trying to locate a single target in a display, fewer distracters would be best. We are concerned with how the visual density of the peripheral information may cause distraction and affect primary task performance.

We also want to determine what effect, if any, the presence of visualizations may have on primary task performance. For peripheral displays, presence time becomes important when it may interrupt or distract from a primary task. Determining limits and recommendations for presence time is particularly important in safety critical systems such as industrial machinery, monitoring stations, and vehicle operation. It is desirable to only show the important peripheral information for an amount of time that will not interfere with the primary work task, yet enable the secondary tasks.

**Pilot Study**

To better understand how people interact with peripheral visualizations in attention-limited environments, we conducted a pilot study in which participants played a video game (primary task) while simultaneously attempting to interpret an information visualization (secondary task). 45 participants performed three rounds of the experiment, with each round displaying a visualization of a different level of visual density. In each round, participants were first given four questions that they would answer using the visualization. Participants played the video game for 30 seconds, then the visualization appeared for 30 seconds while the game continued, and then the visualization disappeared for the final 10 seconds of the game. After each round, participants then an-
Figure 1: Sample information visualizations used in the experiment. Figure a shows a low density visualization, Figure b shows a high density visualization representing the same distribution of data. For the main experiment, each participant saw only one visualization (either high or low density) and answered one question per round. Questions that participants answered included “In which quadrant is the red circle” and “In which quadrant are the yellow objects clustered”. Note that for any quadrant, the high density visualization contains sixteen times as many yellow objects as the low density.

The four questions asked during each round were: identifying the quadrant of the visualization containing an object of a certain color and shape, counting occurrences of certain objects, and identifying the quadrant containing a cluster of certain objects. Since there were four questions to answer per visualization, we decided not to require participants to attempt to memorize the questions before beginning the game. Hence, the questions were displayed on screen during the entire round. We also decided not to require participants to perform extra manual interactions to indicate answers to the questions while playing the game. So participants needed to remember their answers as they discovered them during the round. After the game was over, the questions were again presented along with four possible answers for each question in a multiple choice format.

To better understand how participants behaved, we used a non-head-mounted eye tracking system with some participants to monitor when, where, and for how long they looked at the various regions of the screen (game, questions, visualization). We also collected user performance data for the game and correctness data for the questions.

Lessons learned
In constructing the pilot study, our expectation was that participants would spend most of their time looking at the game. However, after the visualization appeared, participants looked at both the questions and the visualization more than the game. Based on eye-tracking data, participants on average spent 13 percent of the total fixation time looking at the questions. This seemed to impact their game performance, as their block-catching rate dropped by 10% after the visualization was displayed. Furthermore, the high memory load of remembering the answers to the questions until the end of the game may have negatively impacted their performance on the secondary task. These behaviors are not typical of the interactions we intended to model. Hence, in our main experiment, we decided to present only one question per round so that participants could easily memorize the question and remember their answer. This avoids the need to display the question on screen during the game and visualization.

Another interesting observation stemmed from the visualiza-
tion presence times used in the pilot study. In the pilot study, we chose to leave the visualization on-screen for 30 seconds with the expectation that participants would only look at it for a small portion of the time. However, participants repeatedly looked at the visualization and at the questions for the entire on-screen time. Hence, in the main experiment, we chose to limit the visualization presence time to gain a better sense of how quickly participants could effectively process the visualization.

We based our upper bound on a safety regulation established by the Society of Automotive Engineers. It states that in-vehicle navigation system activities should require a maximum of 15 seconds to complete, with eyes-off-the-road accounting for approximately 60 to 75 percent of that time [11]. For one test group, we chose to present the visualization for eight seconds, just under the bound defined by this guideline.

As a lower limit, we considered prior work in which participants were asked to identify trends in data as quickly as possible in single-task situations [12]. In this work, participants typically completed the tasks in less than a second. For our other test group, we chose to have the visualization present for one second since the dual-task situation is more difficult. We hoped to determine if it is feasible for people to find answers to the secondary-task questions in as little as one second or if it required as much as eight seconds (or more).

**Experimental design**

This 2 (time) X 2 (density) X 2 (task type) experiment was designed to determine relative performance on tasks in a dual-task setting. Twenty-eight undergraduate students from a computer science class participated in the experiment for class credit. Participants performed six rounds of playing a video game and answering questions about the visualization that appeared. As in the pilot study, the primary task used in this experiment was a simple video game. The only difference was a faster drop rate of blocks that made the game slightly more difficult.

The secondary task consisted of answering a single question about information that was displayed in a visualization that appeared while playing the game. The questions asked participants to note in which quadrant (upper left, upper right, lower left, lower right) of the visualization a target was located. The target was either a single item (e.g. red square) or a cluster of items (e.g. green objects). As in most visualizations, the picture contained various outlier objects. In each round, participants viewed either a high or low density visualization. High density visualizations contained 320 objects and low density visualizations contained 20 objects. These mock visualizations were designed to mimic common information visualizations such as the Spotfire starfield [1] or maps of landmarks. While the lack of real underlying data may have made the task more difficult, we believe that it was necessary to ensure uniform understanding by all participants.

Each round started with the presentation of the question that the participant would answer using the visualization. The question was then removed and participants then played a simple game as in the pilot study. After 15 seconds of playing the game, the visualization appeared on the screen. Incorporation in the visualization was the answer to the target question. The visualization remained visible for either one or eight seconds, depending on the test group, and then disappeared. Participants then played the game for an additional 10 seconds. The target question then reappeared along with 4 multiple choice answers. See Figure 2 for a screenshot of the experimental setup.

The experiment included three independent variables:

- **Time**: 1 or 8 seconds (time picture was present)
- **Density**: low or high (low=20 objects, high=320)
- **Question**: single or cluster (find single or a cluster)

The time the visualization was present varied between participants: either one or eight seconds. The expectation was that participants would become acclimated to the time. The visualization density (low = 20 objects, high = 320 objects) and question type (find single item, find cluster) were both within-subjects variables. Each participant saw both high and low density visualizations and each saw both types of target question.

The experimental setup included four test groups. The first test group had a visualization presence time of one second, and they saw high then low density visualizations. The second test group differed in that they saw low density before high density visualizations. The third test group was the same as group one except they saw the visualization for eight seconds. Group four was like group two with an eight second visualization presence time. For each round, all participants played the same game, saw the same visualization, and tried to answer the same question. The only things that varied in a given round were the density of the visualization and the time the visualization was visible.

![Figure 2: Game and visualization seen by participants in the experiment. The visualization was only present for either one or eight seconds. Before each round, participants were given a question that they used the visualization to answer.](image)
To measure primary task performance we measured the percent of blocks caught both for the time before the visualization appeared and for the time period after it appeared (including while it was visible). We refer to this as performance. The expectation was that presenting and removing the visualization may be disruptive to the participants. For the secondary task performance we measured the correctness rate for answering the questions. We refer to this as correctness.

RESULTS

The results of this dual-task experiment include measures of performance on the primary task as well as measures on correctness in the secondary task. We compared different conditions using a paired-sample t-test. Analyzing these measures separately allows us to examine the issues described previously: effect of visualization presence on game performance, effect of visualization density on information assimilation, and effect of visualization density on game performance. We expected to find that the presence of the visualization would impact performance on the game. We also expected that locating a single item will be easier in the low density visualizations, and locating a cluster of objects will be easier in the high density visualizations. The following sections summarize the results of the experiment.

Performance

We found no main effect between performance before the visualization appeared and after the visualization appeared for either the one-second group, \( t(13) = 0.563, p < 0.583 \), \( (M_B = 0.594, M_A = 0.586) \), or the eight-second group, \( t(13) = 1.247, p < 0.234 \), \( (M_B = 0.623, M_A = 0.610) \). This is somewhat unexpected because in the pilot study, the presence of the visualization resulted in over 10% difference in performance. Comparing performance on rounds with high density visualizations to rounds with low density visualizations indicates a main effect in the one second conditions, \( t(13) = -2.46, p < 0.029 \), with low density visualizations \( (M = 0.604, SD = 0.091) \) yielding better performance over high density visualizations \( (M = 0.568, SD = 0.071) \). No main effect on performance for density was found in the eight second condition, \( t(13) = -0.363, p < 0.723 \), \( (M_H = 0.609, M_L = 0.618) \). When we compared performance on rounds with the secondary task question to locate a single object to rounds with the secondary task to locate a cluster of objects, we found a main effect in the one second condition, \( t(13) = 2.410, p < 0.031 \), with performance higher when locating a single object \( (M = 0.6, SD = 0.084) \) as compared to locating a cluster \( (M = 0.572, SD = 0.076) \). There was no main effect for question type in the eight second condition, \( t(13) = -0.907, p < 0.381 \), \( (M_S = 0.605, M_C = 0.615) \). See Figures 3 and 4 for a representation of mean performance after the visualization has appeared.

Correctness

To examine whether the order in which participants saw the visualizations affected correctness, we compared them within a single time condition. We found no main effect on correctness for the two orderings, with \( t(6) = 0.471, p < 0.654 \), \( (M_{HI/LO} = 0.6, M_{LO/HI} = 0.548) \) for the one second condition and \( t(6) = -0.548, p < 0.604 \), \( (M_{HI/LO} = 0.929, M_{LO/HI} = 0.952) \) for the eight second condition. As expected, we did find a main effect for time, \( t(13) = -5.252, p < 0.0002 \), with those in the eight second condition \( (M = 0.94, SD = 0.083) \) answering more questions correctly than those in the one second condition \( (M = 0.571, SD = 0.233) \). Comparing correctness on high density visualizations to low density visualizations reveals a main effect in the one second condition, \( t(13) = -2.5, p < 0.027 \), \( (M_H = 0.452, M_L = 0.69) \) as well as in the eight second condition, \( t(13) = -2.687, p < 0.019 \), \( (M_H = 0.88, M_L = 1.0) \), with people answering more questions correctly with low density visualizations. Comparing correctness on ‘find single item’ questions to correctness on ‘find cluster of items’ questions reveals a main effect in both the one and eight second groups. In the one second group we have \( t(13) = -2.219, p < 0.045 \), with more questions answered correctly on ‘find cluster’ questions \( (M = 0.69, SD = 0.332) \) than on ‘find single item’ questions \( (M = 0.452, SD = 0.28) \). In the eight second group we have \( t(13) = -2.687, p < 0.019 \), with more questions answered.
Figure 5: Secondary task correctness based on visualization density and question type. There is a significant difference in correctness in both the 1 and 8 second conditions.

Figure 6: 2x2x2 representation of average correctness based on density, question type and time. Dark arrows indicate statistical significance with the arrowhead indicating the higher correctness rate. Gray arrows indicate marginal significance.

correctly on ‘find cluster’ questions ($M = 1.0, SD = 0.0$) than on ‘find single item’ questions ($M = 0.881, SD = 0.166$). See Figures 5 and 6 for a representation of correctness based on density and question type. We also wanted to examine whether density affected correctness for different question types. For the one second condition with ‘find single item’ questions we find a marginal effect for density, $t(13) = -2.09, p < 0.057$, with people answering more questions correctly with the low density visualizations ($M = 0.643$) than with the high density visualizations ($M = 0.32$). The same comparison in the eight second group produced a main effect, $t(13) = -2.463, p < 0.029$, with more questions answered correctly with low density visualizations ($M = 1.0, SD = 0.0$) than high density visualizations ($M = 0.75, SD = 0.38$). No main effect was found for density in answering ‘find cluster’ questions in either the one or eight second conditions, with $t(13) = -0.486, p < 0.635$ ($M_H = 0.643, M_L = 0.714$) for the one second group. Participants answered all ‘find cluster’ questions correctly (100%) in the eight second condition for both densities. See Figure 7 for a representation of correctness based on density, within a question.

DISCUSSION

Performance

Somewhat surprisingly, introducing the secondary task produced no discernible difference on primary task performance. Increasing the visualization presence time from one second to eight seconds does not seem to effect performance. This contrasts with the pilot study, where visualization presence time was longer (30 seconds) and the primary task was easier. We suspect that the large number of secondary tasks required of the participants in the pilot was the primary contributing factor to this result.

Furthermore, the visual density had a significant impact on performance in the one second conditions after the visualization appeared. People were able to catch more falling blocks when there was a low density visualization on the screen, as compared to when there was a high density visualization. Perhaps the low density visualization was less cognitively demanding and simply distracted the users less. However, in the eight second condition there was no discernible difference in performance for either high or low density visualizations. The longer time span seemed to provide enough time for participants to analyze the visualization.

We found that the question type impacted performance in the one second condition. People caught more blocks when they were trying to locate a single object in the visualization than when locating clusters of objects. Perhaps locating a single item is not as difficult as locating a cluster of objects, or perhaps participants simply did not try as hard – note that they answered less than half of the questions correctly.

As with density, we see that question type produces no discernible difference in performance in the eight second condition. Hence, there must be some form of time pressure on the participants when the visualization is visible for one second. We see significant negative impacts on performance with both density and question type, only in the one second test groups. This short time could have elevated participant stress levels, causing the degradation in performance.

Obviously the secondary task could be done in roughly one second, so having the visualization visible for eight seconds may seem like overkill. We expected that people would
probably look at the visualization several times during the eight second condition and this would reduce performance in those cases. To get a sense of this, we had a handful of participants perform the experiment while having their eye movements recorded with a reflective eye-tracking setup. As suspected, participants looked at the visualization several times in the eight second conditions and only one time in the one second condition. The duration of the fixations on the visualization were also indicative of the behavior. In the one second condition the fixation was between 0.5 and 0.9 seconds. In the eight second condition the fixation times were much larger: 1.5 to 3.0 seconds.

Correctness
In considering correctness on the secondary task, it appears that having the visualization visible for a longer time is beneficial. We also see that visualization density plays an important role in answering the questions. In both the one and eight second conditions we see significantly higher correctness rates for the low density visualizations. This is interesting as we expected to see mixed performance with density, based on the type of question the participants were answering. We expected people to perform better on finding single items with low density visualizations, and better on finding clusters with high density visualizations.

Looking further at question type, we see that in general participants performed better when locating clusters of objects compared to locating a single object. Here again this could be attributed to pre-attentive processing. The task of locating a cluster of objects basically required participants to locate repeated instances of a target color in the display. Shape was not a factor for clusters as it was when locating a single object.

In addition, in the one second condition, we discovered a tradeoff between the primary and secondary tasks for the two question types. For single-item questions, user performance improved but correctness degraded. Whereas, for cluster questions, user performance degraded but correctness improved. For cluster questions, the investment was worthwhile, since the improvement in correctness is much greater than the decrease in performance. Perhaps cluster questions caused more distraction by drawing more of the participants’ attention away from the primary task, but to the benefit of the secondary task. Or, perhaps participants simply gave up on single-item questions and maintained focus on the primary task. In any case, this might indicate that in time pressure situations people have a fixed amount of attentional resources that must be traded off between tasks, especially for visually intensive tasks as in our experimental setup.

CONCLUSIONS AND FUTURE WORK
We conducted this research to explore how quickly and effectively people can interpret an information visualization while performing other tasks. We considered a primary task that demands high attention from the user in order to emphasize the task switching required in dual-task situations. We used abstract information displays in the secondary tasks, and asked participants to answer questions about the visualization.

We wanted to examine how several factors of the visualization would affect a person’s ability to interpret them in an attention-limited environment. In this work, we focused on visual information density, visualization presence time, and secondary task type as attributes to vary. Each of these attributes has particular relevance to the display of visualizations in the periphery.

The following list outlines the most interesting findings of our studies:

- **Peripheral visualizations can be introduced without hindering primary task performance.** The primary task we considered required constant and consistent attention, and it appeared that participants were able to allocate this attention for visualizations presented for either one or eight seconds. This is important as it suggest that people are able to perform non-trivial dual tasks with some efficiency, and gives hope for peripheral visualization design for similar scenarios such as highway driving. It is important to note that if the primary or secondary task required more thought and reasoning, then performance might be affected by a visualization, as was seen in the pilot study and prior work that considered document editing as the primary task [18].

- **Interpreting complex visualizations within one second in a dual-task scenario cannot be done effectively, but with relaxed time constraints can be very effective.** Despite prior work that suggests that the presence of certain visual attributes can be recognized in well under a second [12], we found that in dual-task situations participants perform poorly when only shown a visualization for one second. However, when given eight seconds, they completed the tasks almost perfectly. The longer duration gives users freedom to choose when to task switch, such as at times when their primary task situation is momentarily stable and requires less attention.

- **Lower density displays can result in performance that is as good or better than high density displays in a dual-task scenario.** We found this to be true both when participants were finding single items and finding clusters of items. Note that in our experiments, the cluster-based task was fairly simple: participants were told that a cluster of information existed and they merely needed to identify where. However, as tasks become more numerous and difficult, participants are more likely to become distracted from the primary task as we saw in our pilot study. That presents a unique challenge of breaking down a visualization task into a series of sub-tasks that can be completed independently with low density visualizations and reassembled mentally. This variant of the “chunking” problem, initially studied by Herb Simon [21], has important ramifications for the domain of peripheral information visualization.

- **Finding clusters of visually similar items is easier than locating a single item.** Locating a cluster of items of a single color resulted in more correct answers than locating a single colored shape. This result directly supports prior work by Pomerantz that suggests when dealing with
separable dimensions (such as shape and color), divided attention tasks would take longer [20]. Recall that locating the single item involved both color and shape, which makes it a divided attention task.

Our work has focused on presenting peripheral information to people while they are busy performing some other task that requires significant amounts of attention. We focused on the factors of visual information density and presence time, with information representation the next logical factor to consider. Researchers including Cleveland and Mackinlay have experimentally established visual order-of-precedence rules for standalone visualizations [5, 17], but corresponding rules for visualizations in the periphery are needed. In addition, if the concept of information chunking with low density visualizations is to support increasing quantities of information, then new low-effort peripheral interaction strategies will need to be explored to enable peripheral information navigation with minimal distraction.

A better understanding of the effects of visualizations as secondary displays will impact the increasing development of desktop information management tools. Computer users have long used visualizations like email tools and system load monitors to keep track of information while performing other tasks. As systems like Letizia [16] provide users with additional information on our desktop to help with browsing and communicating, it is becoming increasingly necessary to identify methods for effectively communicating this information with minimal disturbance to other tasks.

With further study, we see this work impacting off-the-desktop situations as well, such as displays in factories and vehicles. In these situations, good guidelines for developing visualizations as secondary displays shift from being beneficial to interpret the visualization peripherally to being essential to do so. Prior studies have looked at the use of icons and other simple visual displays in in-vehicle systems [15]. However, as the information available while driving increases, designers must be ready with safe, effective methods for communicating it to drivers.

REFERENCES


