Appendix II: Relevant Background (Table A1) and Detailed Results for all Included Studies

GV, GPA, and Percentage of Time Spent Glancing at the Forward Roadway

Glance pattern activity: In the study by Smiley et al. (2004), participants made a number of approaches to intersections in an urban environment. During approaches with video billboards (VBs) and passive billboards visible (video approaches), drivers made an average of 53.5 glances to any location, whereas they made 57.3 glances during approaches with only passive billboards visible (non-video approaches). Average glance durations to all locations were also almost identical between scenarios (non-video, 0.38 ± 0.32 seconds; video, 0.37 ± 0.31 seconds). There was therefore no substantial effect of VBs on glance pattern activity (GPA) as compared to passive billboards alone. However, no control condition without billboards was included.

Lee et al. (2007) found no significant differences in GPA among sites with passive billboards, sites with digital billboards (DBBs), sites with on-premises advertising and other visually stimulating non-billboard elements (comparison sites), and sites with no major visually stimulating elements of any kind (baseline sites).

Young et al. (2007) conducted simulated drives in urban, rural, and highway environments, and reported significant direct correlations between the presence of billboards and GPA in all three conditions. There was a main effect of road type, with GPA being significantly higher in urban and highway conditions than in rural conditions. A trend toward an interaction between billboard presence and road type for GPA was found ($0.05 < p < 0.1$), with the GPA-increasing effects of billboards being greater in urban and highway conditions than in rural ones.

Gaze variability: Edquist (2008) found that vertical gaze variability (GV) increased significantly in the presence of both active and passive billboards as compared to control sites, and the effect was significantly greater for active billboards. However, when lead vehicles were present, no increases in vertical GV were observed. Horizontal GV was unaffected by the presence of lead vehicles and billboards of any type. There was no interaction between the instructions a participant received during the simulated drive (to look at billboards vs. no instructions) and the presence of billboards on either horizontal or vertical GV.

Percentage of time spent glancing at the forward roadway: In Smiley et al.'s research (2004), the forward roadway received 77% of all glances and a mean glance duration of 0.37 seconds during non-video approaches, compared to 74% of glances and a mean glance duration of 0.35 seconds on video approaches. These differences were not significant.

Young et al. (2007) indicated that there was no significant effect of the presence of billboards on the percentage of time drivers spent glancing at the forward roadway in any of the three driving conditions (urban, rural, and highway).

In the Reading study by Perez et al. (2012), the percentage of time participants spent glancing at the forward roadway was 86%, 73%, 77%, 92%, 82%, and 80% for freeway no-billboard sites, freeway DBB sites, freeway passive billboard sites, and the same three advertising conditions on arterial roads, respectively. The value for arterial no-billboard sites was significantly greater than the remaining five values. There was no significant effect of billboard type on arterial roads, but on freeways there were significant differences both between DBB and passive billboard sites and between no-billboard sites and the two billboard conditions. For the Richmond study, these percentages were 92%, 82%, 85%, 78%, 76%, and 81%, in the same order as for Reading. The value for freeway no-billboard sites was significantly higher than the other five values, but there were no significant differences among those five. There did not appear to be an effect of time of day on the distribution of glances to the forward roadway in either study (see Perez et al. 2012, figures 13 and 34).

Lee et al. (2007) reported that the percentage of time drivers spent glancing at the forward roadway was 76.7% in baseline sites, 70.1% in comparison sites, 75.5% in DBB sites, and 74.1% in passive billboard sites (differences not significant).

In the study by Edquist et al. (2011), participants composed three groups: novice drivers aged 18-25, drivers aged 25-55, and drivers aged 65+. Half of the drivers were instructed to look at all billboards that appeared and the other half were not given any special instructions with regard to billboards. For five of the six subgroups (all except the middle age group instructed to look at billboards), billboards were associated with significant reductions in the proportion of time drivers spent glancing at the forward roadway. However, this effect was not significantly different between active and passive billboard scenarios.

Chan et al. (2010) found that, when billboard-like distraction tasks were present, experienced drivers spent only 45% of the scenario duration glancing toward the forward roadway. For novice drivers, this figure was 47%. However, no control condition without the tasks was not reported.

Glances at Unexpected Drive-Relevant Stimuli

Divekar et al. (2012) indicated that the presence of a billboard-like distraction task was associated with a significant reduction in the percentage of participants who scanned the roadside for pedestrians in an area designed to suggest high pedestrian activity. In the presence of the distraction task, the percentage of younger, less experienced drivers that scanned for the hazard fell from 37.5% to 8.3% (proportional reduction = 77.86%); for older, more experienced drivers, the percentage fell from 68.4% to 15.0% (proportional reduction = 78.07%). The presence of the distraction task was also associated with significantly decreased success at fixating on a pedestrian running toward the road: the percentage that fixated the hazard fell from 87.5% to 37.5% for the younger cohort (proportional reduction = 57.14%) and from 95.0% to 52.6% for the older cohort (proportional reduction = 44.63%).

Smiley et al. (2004) found that participants who encountered potential-conflict pedestrians or cyclists during video approaches fixated on them without delay. During non-video approaches, three of nine participants who had potential-conflict encounters with pedestrians had delayed fixations. However, potential-conflict pedestrians received a smaller percentage of all glances and a lower average glance duration during video approaches than during non-video approaches.

Glances at Expected Drive-Relevant Stimuli

Edquist (2008) did not find an effect of billboard presence on the latency of participants' first fixations on signs directing them to change lanes, or on the percentage of time participants spent fixating on lane change signs.

Smiley et al. (2004) reported that drivers devoted 0.1% of all glances and an average glance duration of 0.18 ± 0.11 seconds to traffic signs during non-video approaches, compared to 0.3% of all glances and an average glance duration of 0.43 ± 0.22 seconds during video approaches. However, this difference was not significant. There was also almost no difference in the proportion of glances or the average glance duration to traffic signals. Drivers made an insignificantly greater proportion of glances toward the speedometer and rearview mirror during video approaches than during non-video approaches ($0.05 < p < 0.09$). With respect to all fixation targets within the vehicle, however, there was an insignificant trend toward drivers making a smaller percentage of all glances and a shorter average glance on video approaches than non-video approaches.

Glances at Billboards

Long glances at billboards: Perez et al. (2012) conducted two controlled instrumented-vehicle studies (in Reading, Pennsylvania and Richmond, Virginia), each including three independent variables: advertising condition (DBB sites, passive billboard sites, or no-billboard sites; within-subjects); roadway type (arterial or freeway; within-subjects); and time of day (day or night; between-subjects). In the Reading study, the percentage of glances ≥ 0.75 seconds was approximately 12%, 15%, 6%, and 10%, for DBBs during daytime, DBBs at night, passive billboards during daytime, and passive billboards at night, respectively (see Perez et al. (2012), figures 11 and 12). For the Richmond study, these figures were approximately 14%, 0%, 3%, and 4% (see Perez et al. (2012), figures 32 and 33). Additionally, about 6%

of glances lasted approximately 1.33 seconds for DBBs during daytime in Richmond. The longest glance to a DBB in both studies occurred during daytime: in Reading this lasted 1.251 seconds, and in Richmond it lasted 1.335 seconds. For passive billboards, the longest glance in the Reading study lasted 1.284 seconds and occurred at night; in the Richmond study, it lasted 0.801 seconds and occurred during daytime. Perez et al. (2012) also reported data on dwell times, where the dwell time was defined as the sum of the durations of all glances in a string of consecutive glances to a given billboard by a given participant. In Reading, 25 dwell times to DBBs were observed from 15 different participants, with a mean duration of 0.994 seconds (range, 0.418-1.467 seconds); 17 dwell times were made to passive billboards by 11 different participants, with a mean duration of 1.172 seconds (range, 0.418-3.319 seconds). Three dwell times (all to passive billboards) were ≥ 2.0 seconds long. In Richmond, 21 dwell times to DBBs were made by 12 participants, with a mean duration of 1.039 seconds (range, 0.500-2.720 seconds); 13 dwell times were made to passive billboards by 11 participants, with a mean duration of 0.687 seconds (range, 0.450-1.152). One dwell time, to a DBB, was ≥ 2.0 seconds long. In Reading, DBBs and passive billboards did not differ significantly with regard to mean dwell time; however, this difference was significant in Richmond.

Smiley et al. (2004) reported that, on average among the four VBs, 23% of glances were ≥ 0.75 seconds in duration (individual values were 0%, 29%, 43%, and 17%). The mean maximum glance length among the four VBs was 1.10 seconds (0.67, 1.13, 1.47, and 1.13). There was considerable variability among the individual VBs with respect to the durations, but not the number, of glances they attracted. No billboards attracted glances of ≥ 2.0 seconds.

Kettwich et al. (2008) tracked drivers' glances toward VBs as well as three types of passive billboards: advertising pillars (pillars erected on the roadsides and in medians with small, eye-level advertisements), event posters, and company logos. The latter two types of billboards were not defined by Kettwich et al., and it is unclear from their paper what the characteristics of these signs were. It was found that the percentage of all glances of ≥ 0.75 seconds was 20% for advertising pillars, 17% for event posters, 22% for company logos, and 27% for VBs. No glances toward any of the billboards were ≥ 2.0 seconds.

Lee et al. (2007) reported that "the distributions of glance duration were similar across all event types, and there was no obvious pattern of longer glances being associated with any of the event types." However, the authors of this review conducted an independent analysis of the data reported by Lee et al. (2007) in figure 23 of their paper, and found the following patterns of glances ≥ 2.0 seconds in duration: approximately 1.3% of all glances at baseline sites; approximately 3.5% of glances at passive billboard sites; approximately 6.25% of glances at DBB sites; and approximately 7.5% of glances at comparison sites. Wachtel (2007) also reviewed these data and arrived at similar conclusions (2%, 4.5%, 7%, 8%).

In the study by Beijer et al. (2004), the means of the longest glances produced by each billboard were approximately 1.07 ± 0.18 seconds for passive billboards, 0.7 ± 0.3 seconds for rollerbar billboards, 1.19 ± 0.25 seconds for scrolling text billboards, and 1.17 ± 0.25 seconds for VBs. Overall, 88% of participants glanced at one or more billboards for ≥ 0.75 seconds, and 20% of participants glanced at one or more billboards for ≥ 2.0 seconds. The average number of glances per participant per billboard that lasted ≥ 0.75 seconds was 0.19 for passive billboards, 0.38 for rollerbar billboards, 0.25 for scrolling text billboards, and 0.90 for VBs. Unfortunately, the authors did not report the number of glances that were ≥ 2.0 seconds. However, among glances ≥ 0.75 seconds, VBs and rollerbar billboards produced significantly more long glances per participant per billboard than the other two billboard types. The average percentage of all glances that were ≥ 0.75 seconds was 15.4% for passive billboards, 20.7% for rollerbar billboards, 20.1% for scrolling text billboards, and 35.6% for VBs. Finally, there was a great deal of variability among individual billboards within categories in their attraction of long glances.

Chan et al. (2010) found that the mean maximum glance duration toward billboard-like distraction tasks was 3.42 seconds for experienced drivers and 3.75 seconds for novice drivers. Experienced and novice drivers made glances ≥ 2.0 seconds toward the distraction tasks in 81.0% and

81.9% of scenarios respectively. Figure 3 in the study by Chan et al. (2010) indicates that approximately 95% of novice drivers and 97% of experienced drivers made glances toward the distraction tasks of ≥ 0.75 seconds.

In the study by Dukic et al. (2013), approximately half of the participants drove at night and the other half drove during the day. Drivers were exposed both to DBBs and to "other signs," which included several official traffic signs as well as one passive billboard. For three of the four possible combinations of sign type and time of day, the average length of glances made by drivers was > 0.75 seconds. The greatest average glance length among the four possible combinations was for DBBs at night, at 1.0 seconds per glance per sign. The average of the longest glances made by each driver were 0.95 ± 0.78 seconds for DBBs during the day, 0.62 ± 0.55 seconds for other signs during the day, 1.00 ± 0.73 seconds for DBBs at night, and 0.70 ± 0.43 seconds for other signs at night.

Divekar et al. (2012) found that, for both driver experience groups, approximately 95% of all glances made at the distraction tasks were ≥ 0.75 seconds and 82.7% of glances made at the distraction tasks were ≥ 2.0 seconds. For both groups, nearly 100% of drivers made at least one glance ≥ 0.75 seconds during each distraction task. There was at least one glance ≥ 2.0 seconds during each distraction task for 92.8% of novice and 89% of experienced drivers. Though these rates of long glances are not likely to be representative of naturalistic driving behavior, it is noteworthy that participants in this study generally chose to make a single very long glance to complete each distraction task, even though they had time to make multiple shorter and potentially safer glances back and forth between the roadway and the task.

Mean number and duration of glances at billboards: In the Reading study by Perez et al. (2012), mean glance durations were 0.389 seconds, 0.387 seconds, 0.341 seconds, and 0.370 seconds, for DBBs during the day, DBBs at night, standard billboards during the day, and standard billboards at night, respectively. In the Richmond study, these figures were 0.440 seconds, 0.333 seconds, 0.313 seconds, and 0.325 seconds. In the Reading study, DBBs and standard billboards each received about 2.4% of all glances. Each dwell time on a DBB comprised a mean of 2.40 glances per participant per billboard (range, 2-5) while passive billboards dwell times comprised a mean of 3.47 glances per participant per billboard (range, 2-8). In the Richmond study, 2.5% of all glances were made to DBBs and 1.5% of all glances were made to passive billboards. Dwell times to DBBs comprised a mean of 2.86 glances per participant per billboard (range, 2-6), while passive billboard dwell times comprised a mean of 2.31 glances per participant per billboard (range, 2-3).

Kettwich et al. (2008) reported mean glance durations of 0.953 seconds for advertising pillars, 0.656 seconds for event posters, 0.591 seconds for company logos, and 0.733 seconds for VBs. The authors did not report whether these significantly differed.

Beijer et al. (2004) found no significant differences among passive billboards, rollerbar billboards, scrolling text billboards, and VBs in mean or maximum glance duration. However, the mean number of glances per participant per billboard was significantly lower for passive billboards than for the other three billboard types. The mean number of glances per participant per billboard was 0.64 for passive billboards, 1.32 for rollerbar billboards, 1.31 for scrolling text billboards, and 1.44 for VBs. The mean glance duration was 0.49 seconds for passive billboards, 0.53 seconds for rollerbar billboards, 0.50 seconds for scrolling text billboards, and 0.64 seconds for VBs.

Smiley et al. (2004) found that VBs received 2% of all glances made during video approaches, with an average glance length of 0.48 ± 0.35 seconds. Passive billboards received 1% of all glances and a mean glance duration of 0.58 ± 0.54 seconds during non-video approaches, compared to 0.2% of glances and a mean duration of 0.27 ± 0.17 seconds during video approaches. On average among the four VBs, 41.7% of participants exposed to them glanced at them. Among these, there was an average of 1.9 glances per participant per billboard.

Lee et al. (2007) found no significant differences among site types in mean number of glances toward events of interest on either side of the road. For sites where the events of interest were on the left side of the road, the mean number of glances per site to the left forward of the vehicle was 1.18 for baseline sites, 1.36 for comparison sites, 1.56 for DBB sites, and 1.37 for passive billboard sites. For sites where the events of interest were to the right side of the road, the mean number of glances per site to the right forward of the vehicle was 1.44 for baseline sites, 1.42 for comparison sites, 1.48 for DBB sites, and 1.61 for passive billboard sites.

Lee et al. (2004) reported finding no significant differences in the mean number or duration of glances at billboard sites and comparison sites, but did not provide more specific data.

Chattington et al. (2009) reported that VBs received a mean of 1.67 ± 2.83 glances per participant per billboard, which was significantly greater than the 1.11 ± 2.28 glances per participant per billboard made to passive billboards. There was no significant difference between the mean duration of glances made to VBs (0.27 ± 0.22 seconds) and those made to passive billboards (0.28 ± 0.35 seconds). However, as a proportion of the amount of time for which each billboard was visible, drivers looked for significantly longer at VBs than at passive billboards.

Dukic et al. (2013) reported that drivers during the day made an average of 2.68 ± 1.93 glances at DBBs and an average of 1.26 ± 0.45 glances toward the other signs. During the night, drivers made an average of 2.10 ± 1.37 glances at DBBs and an average of 1.50 ± 0.88 glances at the other signs. On average during the day, drivers spent a total of 2.23 ± 2.26 seconds looking at each DBB and 0.87 ± 0.73 seconds looking at each of the other signs. During the night, drivers spent a total of 2.09 ± 2.21 seconds glancing at each DBB on average, vs. 1.16 ± 0.74 seconds glancing at each of the other signs. By dividing the average total time spent glancing toward a sign by the average number of glances at a sign, it is possible to calculate the average glance lengths toward each type of sign in each time of day condition: 0.83, 0.69, 1.0, and 0.77 seconds per glance per sign for DBBs during the day, other signs during the day, DBBs at night, and for the other signs at night, respectively. Overall, DBBs attracted a significantly greater number of glances than the other signs. However, there was no significant difference between DBBs and the other signs in the proportion of the time during which the signs were visible that the drivers spent looking at them. Moreover, there were no significant differences in any of the visual behavior variables between night and day. Finally, figures 3 and 4 in the paper by Dukic et al. (2013) indicated that there was substantial variability among individual signs within sign-type categories with respect to all of the visual behavior variables studied.

Summary of Results

There was strong evidence that mean glance duration did not differ between active and passive billboards; that approximately 10-20% of all glances at billboards were ≥ 0.75 seconds in length and that active billboards were especially likely to attract long glances; that there was no interaction between billboard activity and percentage of time spent glancing at the forward roadway, and also no interaction between billboard activity and GPA; and that there was quite substantial variability within billboard categories (e.g., active vs. passive) with respect to their impacts on visual behavior.

The following may be tentatively concluded: that active billboards attracted a greater number of glances on average than passive billboards; that there was no main effect of billboard presence on the proportion of time drivers spent glancing at the forward roadway; that billboards might in some cases substantially impair drivers' detection of unexpected stimuli; that billboards did not change drivers’ visual behavior in relation to expected drive-relevant stimuli (e.g., mirrors, instruments, and official road signs); and that billboards, especially if active, increased vertical GV but that neither type of billboard increased horizontal GV.

Finally, the “typical” passive billboard might attract an average of about 1.3 glances per driver at an average length of 0.51 seconds each, while a “typical” active billboard might attract an average of about 2.23 glances per driver at an average length of 0.54 seconds each.

This review did not yield enough evidence for conclusions to be made on the extent to which passive and active billboards may attract glances ≥ 2.0 seconds in duration, or on the main effect of billboard presence on GPA.

REFERENCES

1. Beijer D, Smiley A, Eizenman M. Observed driver glance behavior at roadside advertising signs. *Transport Res Rec.* 2004;1899:96-103.
2. Chan E, Pradhan AK, Pollatsek A, Knodler MA, Fisher DL. Are driving simulators effective tools for evaluating novice drivers' hazard anticipation, speed management, and attention maintenance skills. *Transp Res Part F Traffic Psychol Behav*. 2010;13(5):343-353.
3. Chattington M, Reed N, Basacik D, Flint A, Parkes A. *Investigating driver distraction: the effects of video and static advertising*. London, England: Transport Research Laboratory; 2009. Report No. PPR409.
4. Divekar G, Pradhan AK, Pollatsek A, Fisher DL. Effect of external distractions: behavior and vehicle control of novice and experienced drivers evaluated. *Transport Res Rec.* 2012;2321:15-22.
5. Dukic T, Ahlstrom C, Patten C, Kettwich C, Kircher K. Effects of electronic billboards on driver distraction. *Traffic Inj Prev*. 2013;14:469-476.
6. Edquist J. *The effects of visual clutter on driving performance* [dissertation]. Melbourne, Australia: Monash University; 2008.
7. Edquist J, Horberry T, Hosking S, Johnston I. Effects of advertising billboards during simulated driving. *Appl Ergon*. 2011;42:619-626.
8. Kettwich C, Klinger K, Lemmer U. Do advertisements at the roadside distract the driver? *Proc. SPIE*. 2008;7003:1-5.
9. Lee SE, McElheny MJ, Gibbons R. *Driving performance and digital billboards: final report*. Blacksburg, VA: Virginia Tech Transportation Institute; 2007.
10. Lee SE, Olsen ECB, DeHart MC. *Driving performance in the presence and absence of billboards*. Blacksburg, VA: Virginia Tech Transportation Institute; 2004.
11. Perez WA, Bertola MA, Kennedy JF, Molino JA. *Driver visual behavior in the presence of commercial electronic variable message signs (CEVMS)*. Washington, DC: National Highway Traffic Safety Administration; 2012. Report No. FHWA-HRT-
12. Smiley A, Smahel T, Eizenman M. The impact of video advertising on driver fixation patterns. *Transport Res Rec.* 2004;1899:76-83.
13. Wachtel J. *A critical, comprehensive review of two studies recently released by the outdoor advertising association of america*. Berkeley, CA: The Veridian Group; 2007. Project No. AX137A51
14. Young MS, Mahfoud JM. *Driven to distraction: determining the effects of roadside advertising on driver attention*. London, England: Brunel University; 2007.

Table A1: Relevant background information for each article included in this review, sorted by methodology, then by year of publication, and then alphabetically by the last name of the primary author. For studies that contributed data to more than one analysis category, these categories are listed in the order in which they are discussed in the review. Sample sizes reflect the number of participants who began the study and not necessarily the number of participants for whom data were eventually analyzed.

Primary Author	Year	Title	Visual Attention Categories	Methodology	Sample Size
Divekar, G.	2012	Effect of external distractions: Behavior and vehicle control of novice and experienced drivers evaluated	Attention to unexpected drive-relevant stimuli; Long glances at billboards	Simulator	48 (younger cohort = 24, older cohort = 24)
Edquist, J.	2011	Effects of advertising billboards during simulated driving	Percentage of time spent glancing at the forward roadway	Simulator	48 (ages 18-25 = 16, ages 25-55 = 16, ages 65+ = 16)
Chan, E.	2010	Are Driving Simulators Effective Tools for Evaluating Novice Drivers' Hazard Anticipation, Speed Management, and Attention Maintenance Skills?	Percentage of time spent glancing at the forward roadway; Long glances at billboards	Simulator	24 (novices aged 16-18 = 12, experienced drivers aged 21+ = 12)
Chattington, M.	2009	Investigating driver distraction: The effects of video and static advertising	Mean number and duration of glances at billboards	Simulator	48
Edquist, J.	2008	The Effects of Visual Clutter on Driving Performance	GV; Attention to expected drive-relevant stimuli	Simulator	48 (probationary licensees = 16, full licensees = 16, older full licensees = 16)
Young, M.S.	2007	Driven to distraction: Determining the effects of roadside advertising on driver attention	GPA; Percentage of time spent glancing at the forward roadway	Simulator	48
Dukic, T.	2013	Effects of Electronic Billboards on Driver Distraction	Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	41
Perez, W.A.	2012	Driver Visual Behavior in the Presence of Commercial Electronic Variable Message Signs (CEVMS)	Percentage of time spent glancing at the forward roadway; Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	84 (Richmond = 41, Reading = 43)
Kettwich, C.	2008	Do advertisements at the roadside distract the driver?	Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	16
Lee, S.E.	2007	Driving Performance and Digital Billboards Final Report	GPA; Percentage of time spent glancing at the forward roadway; Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	36 (younger cohort = 18, older cohort = 18)
Beijer, D.	2004	Observed Driver Glance Behavior at Roadside Advertising Signs	Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	25
Lee, S.E.	2004	Driving Performance in the Presence and Absence of Billboards	Mean number and duration of glances at billboards	Instrumented vehicle	36
Smiley, A.	2004	The Impact of Video Advertising on Driver Fixation Patterns	GPA; Percentage of time spent glancing at the forward roadway; Attention to unexpected drive-relevant stimuli; Attention to expected drive-relevant stimuli; Long glances at billboards; Mean number and duration of glances at billboards	Instrumented vehicle	16