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The Impact of Billboards on Driver Visual Behavior: A Systematic Literature Review

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Abstract

Objective—External distraction appears to affect at least 6–9% of distraction-affected motor vehicle collisions. Billboards may be good models for studying external distraction in general, and it is also desirable to understand billboard-related distraction per se. However, there has not yet been a clear consensus on the scope of billboard-related distraction or its dynamics with respect to characteristics of drivers, billboards, traffic, and the roadway. To narrow these knowledge gaps, a systematic literature review was conducted on billboard-related changes in driver visual behavior.

Methods—A systematic literature search yielded 443 results, of which 8 studies met all inclusion criteria. Five studies meeting all inclusion criteria were later identified and added. Results were analyzed in terms of 4 categories of visual behavior: (1) gaze variability (GV), glance pattern activity (GPA), and percentage of time spent glancing at the forward roadway; (2) glances at unexpected drive-relevant stimuli; (3) glances at expected drive-relevant stimuli; and (4) glances at billboards.

Results—There was considerable evidence that about 10–20% of all glances at billboards were ≥0.75 s, that active billboards drew more glances and more long glances (≥0.75 s, ≥2.0 s) than passive billboards but did not attract a longer average glance, and that there was large variability among individual billboards within categories (e.g., active vs. passive). The extent to which billboards attracted glances ≥ 2.0 s was uncertain. There was tentative evidence that billboards did not affect GPA, glances at expected drive-relevant stimuli, or the proportion of time drivers spent glancing at the forward roadway and that they did affect vertical GV and glances at unexpected drive-relevant stimuli.

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Supplemental Materials

Supplemental data for this article can be accessed on the publisher's website.

Conclusions—Generally, billboard-related distraction appeared to be minor and regulated by drivers as the demands of the driving task changed. However, this review's findings suggest that this may not be true in all cases. Future research should emphasize the tails of the distribution in addition to average cases, in terms of both the analysis of visual behavior and the complexity of driving tasks. Further research is also needed to understand the effects of billboard design, driver characteristics, and road and traffic context.

Keywords

driving; distraction; visual behavior; billboards; advertising; traffic safety

Introduction

The purpose of this review is to clarify the relationship between billboards and driver distraction in the United States, and the implications of such distraction for traffic safety, by summarizing current knowledge on the effects of billboards on driver visual behavior. Implications of findings for policy and future research on billboard-related distraction, as well as external distraction in general, are discussed.

Defining Distraction and Billboards

To compare findings among studies on distracted driving, as well as to interpret correctly the results of any given study, it is helpful to refer to a specific and commonly accepted definition of driver distraction. Pettitt et al. (2005) proposed the following definition: (1) a "delay by the driver in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle (the driving task)" that is (2) "due to some event, activity, object or person, within or outside the vehicle [the distracting agent]"; (3) "that compels or tends to induce the driver's shifting attention away from the fundamental driving tasks [i.e., navigating and maintaining safe control of the vehicle]"; (4) "by compromising the driver's auditory, biomechanical, cognitive or visual faculties [the four fundamental systems by which the driver senses, processes, plans and acts to complete the driving task], or combinations thereof" (p. 11).

Distracting agents may be either relevant to the driving task (e.g., in terms of navigation, guidance, control, safety, or traffic regulation) or irrelevant; in either case, they may be expected or unexpected. Furthermore, distractions need not result in a motor vehicle collision (MVC) or other traffic safety incident. With these clarifications, the definition by Pettitt et al. (2005), which is consistent with other more recent definitions (e.g., Hanowski 2011), serves as the basis for all discussions of driver distraction herein. In this review, *visual behavior* indicates the overall way in which the driver moves his eyes to view the environment, and *visual distraction* refers to the situation that occurs when visual behavior changes in response to a distracting agent in a way that causes a delay or failure in the visual perception of drive-relevant information.

The term *billboard* herein refers to any off-premises external-to-vehicle advertising sign that is permanently constructed along a roadway and conveys visual information. To facilitate discussion of the effects of billboard animation and message changes, this review defines 2

categories of billboards as follows: a billboard is “active” if its display changes frequently enough (e.g., by animation of one advertisement or alternations among different advertisements) that a given driver could plausibly see more than one display on the billboard during his approach; a billboard is “passive” if it does not meet this criterion. Active billboards can be digital billboards (DBBs) or signs that change displays mechanically (e.g., “rollerbar” or “tri-vision” billboards), though some billboards using these technologies change messages infrequently enough that they would be considered passive for the purposes of this review. This review further defines a special category of active billboards (“video billboards”) as those displaying full motion. Although such displays may be used on DBBs in some countries, as well as on on-premises signs in the United States, their use on DBBs in the United States is prohibited by most federal–state agreements required by the Highway Beautification Act (Sisiopiku et al. 2013) and discouraged by the Outdoor Advertising Association of America (2014).

Rationale for the Review

U.S. MVC records (e.g., the Fatality Analysis Reporting System [FARS] and General Estimates System [GES]) suggest that external distractions affect approximately 6–9% of all distraction-affected MVCs or approximately 4% of all MVCs attributable to any driver error. In 2011, this would have represented at least 49,164 MVCs (NHTSA 2008, 2013). Furthermore, it is likely that these figures underrepresent both distraction in general and external distraction in particular as a cause of MVCs (Wallace 2003). In a review of laboratory experiments, instrumented-vehicle studies, surveys, and MVC records, Wallace (2003) suggested that “it is likely that distraction accounts for roughly between 10% and 30% of all accidents” (p. 33), in comparison with the 2011 FARS-GES estimate of 15.5% (NHTSA 2013). If Wallace’s estimate is accurate, the percentage of MVCs involving external distractions may exceed FARS-GES estimates by a similar or greater proportion.

Though the traffic safety impact of external distraction has been at least approximately established, many knowledge gaps must be addressed before effective steps can be taken to reduce this impact. Specifically, it is largely uncertain how external distraction is affected by the characteristics of drivers (e.g., age), distracting agents (e.g., dynamic or static), roadways (e.g., urban or rural; presence of intersections), and traffic (Wachtel 2009; Wallace 2003). It is also desirable to supplement evidence from MVC records on the traffic safety impact of external distractions with evidence collected in real time during experiments or observational studies. Studying the relationship between billboards and visual behavior, in addition to addressing these knowledge gaps as they apply to one potentially prominent type of external distracting agent, may provide clues to both the scope and dynamics of external distraction in general. Billboards are common and designed to attract attention, relatively easy to implement in a simulator (although even the most realistic simulators available today cannot accurately simulate the brightness, contrast, and legibility of modern DBBs), and fixed in location along the roadway. Furthermore, they can be found, built, or simulated in different roadway and traffic contexts and include various discrete and easily modified attributes (e.g., font size, color, apparent brightness), which may help in understanding which particular visual elements of an external agent make it distracting. In turn, visual behavior may be measured quantitatively and in real time, should be highly sensitive to

billboard-related distraction because billboards are exclusively visual media, and can be used for other external agents because external distraction is predominantly (albeit not exclusively) visual (Wallace 2003).

Selected Aspects of Driver Visual Behavior

Aspects of visual behavior considered in this review fell into 4 categories: (1) gaze variability (GV), glance pattern activity (GPA), and percentage of time spent glancing at the forward roadway; (2) glances to unexpected drive-relevant stimuli; (3) glances to expected drive-relevant stimuli; and (4) glances at billboards.

GPA was measured as the number of glances made to any location per unit of time. GV was measured as the standard deviation of the directions of all glances made during a given period of time, where the direction of a glance was measured as the angle between the point of fixation and an imaginary reference point located at eye level directly in front of the vehicle. GV can be measured separately along the vertical (down the road in front of the vehicle) and horizontal (toward the roadsides) axes. For example, if a certain stimulus increases horizontal GV and decreases vertical GV, a driver will respond to that stimulus by glancing more frequently and more widely toward the roadsides and less frequently and less distantly down the road in front of the vehicle (Edquist 2008).

Glances at stimuli that were unexpected and drive relevant, including emergent hazards (though not all unexpected stimuli are drive relevant or hazardous), were described in terms of the proportion of drivers who glanced at such stimuli and the latency of first glances. Glances at expected drive-relevant stimuli were described in terms of the proportion of time drivers spent glancing at such stimuli, the proportion of drivers who glanced at them, and the latency of first glances at drive-relevant signs. For both categories, the drive relevance and expectedness of stimuli were determined for each study on an individual basis, in consideration of the tasks and instructions given to participants.

Finally, the analysis characterized glances at billboards. Of particular interest were very long glances, which were defined with respect to 2 thresholds: 0.75 s or longer in duration, because 0.75 s has been suggested as the minimum perception–reaction time (PRT) for a vehicle slowing ahead of the driver (Smiley et al. 2004), and 2.0 s or longer in duration, because glances away from the roadway of this length have been shown in naturalistic studies to be especially associated with MVCs and other traffic incidents (Klauer et al. 2006). When possible, this review discusses study results in terms of both thresholds. The outcome variables in this section were the duration and number of glances at a billboard or billboard-like stimulus.

Appendix I (see online supplement) provides supplementary information about billboards in the United States, alternative methods for the study of billboard-related distraction, and evidence from MVC records on the traffic safety impact of external distraction.

Methods

For this review, studies in English that met the following criteria were considered: (1) included driving in a simulator or in an instrumented vehicle; (2) included independent variables related to the presence and/or characteristics of billboards (e.g., passivity vs. activity); (3) included at least one of the visual behavior outcome variables defined above; and (4) were peer-reviewed manuscripts, academic works, or government reports. The literature search was conducted in October 2012 using the search term “driv* AND (billboard* OR advert*) AND (distract* OR attent*)” in the following databases: Scopus, the Transportation Research International Documentation database, PsycInfo, and PsycArticles.

The 443 initial search results were first evaluated for relevance based on their titles. The full texts of those articles identified as candidates for inclusion were again reviewed to determine whether each met all inclusion criteria. Each study meeting inclusion criteria was analyzed with respect to one or more of the following categories of visual behavior: GV, GPA, and percentage of time spent glancing at the forward roadway; glances at unexpected drive-relevant stimuli; glances at expected drive-relevant stimuli; and glances at billboards.

Results

Literature Search Results

The literature search resulted in 8 articles that met all inclusion criteria (Figure 1). In addition, 5 studies that met all inclusion criteria were later identified and added to the review. Due to limitations of space, only summarized results for each category of visual behavior are reported herein. Appendix II (see online supplement) contains detailed explanations of the relevant results of each study, as well as a table (Table A1, see online supplement) summarizing the methodology, sample size, and categories of output used by each.

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

Three studies (Lee et al. 2007; Smiley et al. 2004; Young et al. 2007) reported data on GPA. Overall, there was not conclusive evidence on the question of whether billboards were associated with significant changes in GPA. Despite the uncertainty as to whether a main effect of billboard presence on GPA exists, all available evidence indicated that active and passive billboards did not differ in their effects on GPA. Tentative evidence was found for both a main effect of road context and an interaction between road context and billboard presence, with GPA being higher and more affected by billboards on urban roads and motorways than rural roads.

One study (Edquist 2008) reported data on GV. Vertical GV increased significantly in the presence of both active and passive billboards 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. Finally, 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.

Six studies (Chan et al. 2010; Edquist et al. 2011; Lee et al. 2007; Perez et al. 2012; Smiley et al. 2004; Young et al. 2007) reported the percentage of time drivers spent glancing at the forward roadway. Overall, there was tentative evidence that the presence of billboards did not significantly affect the percentage of time drivers devoted to glancing at the forward roadway; there was strong (but not unanimous) evidence that active and passive billboards did not differ in their effects on this percentage.

Glances at Unexpected Drive-Relevant Stimuli

Two studies (Divekar et al. 2012; Smiley et al. 2004) reported data on the effects of billboards on glances at unexpected drive-relevant stimuli. Divekar et al. (2012) found that DBB-like tasks significantly reduced the percentage of drivers who fixated on potential conflict pedestrians appearing by the road-sides, and the percentage who scanned the roadsides when environmental context suggested pedestrian presence was likely. Proportionally, this reduction did not differ in size between experienced and inexperienced drivers when pedestrian presence was merely suggested; however, when pedestrians actually appeared, the reduction was greater for the inexperienced group. Smiley et al. (2004) did not find clear evidence of an effect of billboards on the latency of fixations to potential conflict pedestrians and cyclists, though their data did indicate that active and passive billboards did not differ substantially in this regard.

Glances at Expected Drive-Relevant Stimuli

Two studies (Edquist 2008; Smiley et al. 2004) reported data on the effects of billboards on drivers' glances at expected drive-relevant stimuli. Billboards did not have significant effects in either study on the number, duration, or latency of glances made at these stimuli or on the proportion of time spent glancing at them. Furthermore, there were no differences between active and passive billboards.

Glances at Billboards

Long Glances at Billboards—Eight studies (Beijer et al. 2004; Chan et al. 2010; Divekar et al. 2012; Dukic et al. 2013; Kettwich et al. 2008; Lee et al. 2007; Perez et al. 2012; Smiley et al. 2004) reported data regarding long glances toward billboards. There was considerable evidence that 10–20% of glances made at billboards were ≥ 0.75 s in duration. Two studies (Chan et al. 2010; Divekar et al. 2012) reported very high rates of glances ≥2.0 s, but both used distraction tasks that seem likely to have≥been substantially more distracting than real billboards (i.e., tasks in which participants were instructed to view a target and search for specific letters within a grid). Data reported by Lee et al. (2007) also indicated that approximately 3.5% of glances made at passive billboards and approximately 6.25% of glances made at active billboards were ≥2.0 s. However, none of the remaining 5 studies in this section reported any glances ≥2.0 s. In general, active billboards seemed more likely than≥passive ones to attract long glances; however, there appeared to be substantial variability in this regard within both groups.

Mean Number and Duration of Glances at Billboards—Eight studies (Beijer et al. 2004; Chattington et al. 2009; Dukic et al. 2013; Kettwich et al. 2008; Lee et al. 2004, 2007; Perez et al. 2012; Smiley et al. 2004) reported the mean number and duration of glances made at billboards. In general, there was tentative evidence that active billboards attracted a greater number of glances than passive billboards. Strong evidence was found that there was no significant difference between active and passive billboards in mean glance duration, though active billboards tended to be viewed for a greater total amount of time because they attracted a greater number of glances. For passive billboards, the mean number of glances per participant per billboard ranged from 0.64 to 3.47 (mean, 1.66). For active billboards, the range was 1.31 to 2.86 glances (mean, 1.88). The range of mean glance durations was 0.27 to 0.953 s (mean, 0.51) for passive billboards and 0.27 to 1.0 s (mean, 0.54) for active billboards. Finally, there was once again strong evidence of substantial variability among individual billboards within categories.

Discussion

In most situations, visual behavior measures did not seem to indicate that drivers were dangerously distracted by billboards. Billboards did not appear to affect the overall percentage of time spent glancing at the forward roadway, and drivers seemed able to self-regulate their attention to billboards when they realized that the demands of the driving task had increased; for example, to attend to lead vehicles or to view navigation-related, regulatory, or warning signs. Furthermore, drivers tended to make several short, consecutive glances to billboards rather than fewer, longer glances. The mean lengths of these glances probably do not suggest a traffic safety concern, especially because drivers may be able to attend to the forward roadway using peripheral vision even while glancing at a billboard. However, billboards may pose a considerable risk when PRTs near 0.75 s are required or when the driving task suddenly and unexpectedly becomes more difficult after a period of relatively low complexity.

In situations where passive billboards were distracting, active billboards appeared to be even more so: they were more likely to attract long glances; they attracted a greater number of glances on average; and they had greater effects on vertical GV. However, active and passive billboards did not differ in any other ways studied in this review; that is, where passive billboards were not distracting, active billboards generally did not appear to be either.

This review yielded only limited evidence on the effects of road and traffic context or driver characteristics on billboard-related distraction. Where studies did investigate these effects of context and individual characteristics, they did not reveal any consistent patterns of differences among groups (e.g., old vs. young drivers; highways vs. arterial roads).

Future Research

Further research is needed regarding the extent to which billboards attract glances ≥ 2.0 s, due to the safety impact of such glances found by Klauer et al. (2006). Research is also needed regarding the visual behavior categories for which tentative or inconclusive evidence was found. In particular, future research including GV as an outcome variable would be

valuable, because of its potential to yield information about changes in drivers' roadway-scanning patterns. In terms of study methodologies, there is a need both for more studies that are truly naturalistic and for the continued development of more realistic driving simulators (e.g., to permit a more accurate representation of the brightness, contrast, and legibility of modern DBBs). Though both controlled instrumented-vehicle and simulator studies offer unique and important qualities, current methodologies (i.e., those employed by the studies analyzed in this review) make it likely that driver behavior will tend to be unrealistically cautious in the former and unrealistically careless in the latter.

Because of this review's finding of high heterogeneity among billboards even within the categories typically studied, it is critical that future research consider individual variability in billboard design and context rather than treating all billboards of a given type as being equal. Driver characteristics and road and traffic context may also require finer treatment, though this review did not indicate how much variability in distraction effects might be attributable to variability in these areas. One way of understanding variability in all these areas might be to use the quantitative visual behavior measures reported in this review (e.g., the mean number and duration of glances made at billboards) as benchmarks against which to compare the distracting effects of a billboard as study conditions are varied. In consideration of the findings regarding the prevalence of long glances, it is also important that future studies emphasize tails of the distribution (see Horrey and Wickens 2007) in addition to central tendencies, in terms of both the analysis of driver visual behavior and the demands placed on the driver during the study. That is, long glance durations and other extreme instances of an outcome variable should be considered separately from its mean, and studies should include the situations in which billboards are most likely to be distracting (e.g., those with heavy traffic, intersections, or high pedestrian activity).

Limitations of this Review

Origin of Studies—For a review that best informs U.S. policy and research, restricting study collection to U.S. research would be desirable due to variability among different areas of the world in many factors that could affect the relationships under study. However, restricting the literature search in this way would have left too small a body of research to provide a useful review. Therefore, no explicit restriction was made based on a study's place of origin, though the search was limited to studies published in English to allow for accurate analysis. Ultimately, research conducted outside of the United States was presented in 8 of the 13 articles included in this review (Beijer et al. 2004; Chattington et al. 2009; Dukic et al. 2013; Edquist 2008; Edquist et al. 2011; Kettwich et al. 2008; Smiley et al. 2004; Young et al. 2007).

Methodological Issues in Included Studies—The studies included in this review should be interpreted in acknowledgment of the limitations of their general methodologies; that is, driving simulations or controlled instrumented-vehicle studies. In the former, conditions can be controlled precisely but drivers might not behave as they would on a real drive; in the latter, participants drive vehicles that are not their own, experiments are of relatively short duration, researchers are present in the vehicles, and data collection instruments are often unconcealed. Furthermore, most included studies did not report on

their eye-tracking data reduction processes in sufficient detail to allow assessment of differences in how each defined a *glance* (i.e., in terms of the duration and localization required for a set of data points to be considered a glance) or coded a glance's location.

Unique methodological problems also existed in at least 3 included studies. In addition to the general limitations of simulator studies, the studies by Divekar et al. (2012) and Chan et al. (2010) used stimuli that were likely to have substantially greater distraction effects than real billboards, though they were intended to engage drivers in the same way as would scanning a DBB. In both studies, the stimuli used were smaller but somewhat closer to the roadway than real billboards, and each stimulus contained a 5 × 5 grid of large letters. In each study, participants were instructed to look at these stimuli when they appeared and to count the number of occurrences of 3 specified letters on each sign, with some signs containing those letters and some not. Because the tasks and instructions given to participants in the studies by Divekar et al. (2012) and Chan et al. (2010) seem unrepresentative of viewing real billboards, the results of those studies should be interpreted conservatively. The study by Lee et al. (2007) has been criticized by other reviewers for methodological and analytical flaws (see, e.g., Wachtel 2007). The most important of these flaws for the purposes of this review concerned the analysis of the prevalence of long glances. Conclusions regarding Lee et al.'s (2007) findings were based on reanalysis of their original data by this review's authors, the results of which were consistent with reanalysis performed by Wachtel (2007).

Potential Bias—The studies by Lee et al. (2004, 2007) were funded by and prepared for the Outdoor Advertising Association of America, which has a business interest in research and policy on billboards.

This review concurs with previous literature reviews (e.g., Sisiopiku et al. 2013; Wachtel 2009; Wallace 2003) in indicating that billboards likely pose a modest, though nonnegligible, traffic safety risk through driver distraction. This risk is likely to be low in most situations but considerable when very fast PRTs are required or when a period of simple driving is followed by an unexpected or sudden period of complexity. Furthermore, the results of this review indicate that this risk can vary widely based on individual billboard characteristics and possibly also by driver, road, and traffic characteristics. Future research should emphasize an understanding of these sources of variability, as well as the tails of the distribution in terms of visual behavior analysis and driving task complexity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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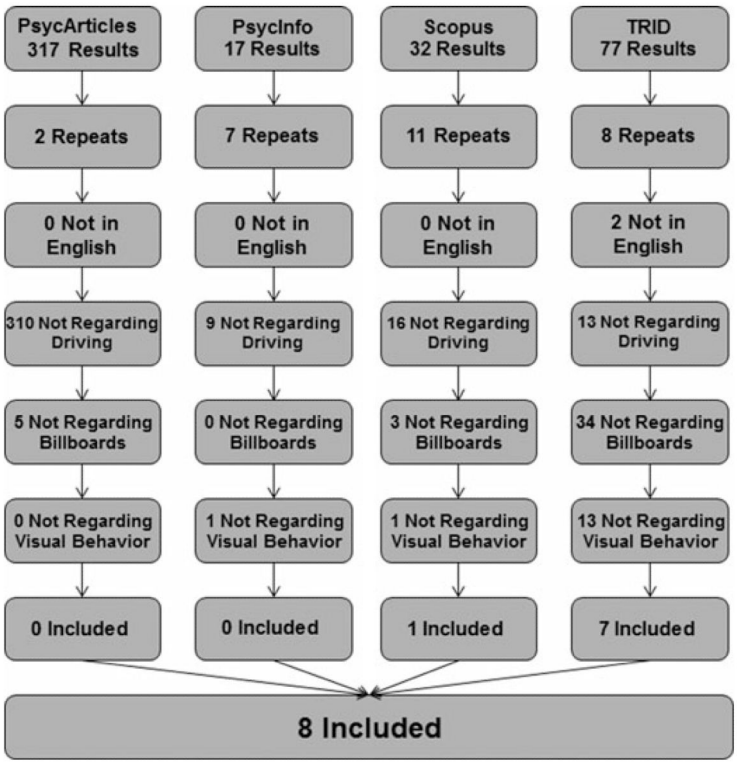

Fig. 1.

Flowchart depicting the literature exclusion process, with the number of results from each source that were excluded based on each criterion.