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**The VR Billboard Paradigm:
Using VR and Eye-tracking to Examine the Exposure-Reception-Retention Link
in Realistic Communication Environments**

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Abstract

Exposure is the cornerstone of media and message effects research. If a health, political, or commercial message is not noticed, no effects can ensue. Yet, existing research in communication, advertising, and related disciplines often fails to measure exposure and demonstrate the causal link between quantified exposure to outcomes because actual exposure (i.e., whether recipients were not only exposed to messages but also took notice of them) is difficult to capture. Here, we harness Virtual Reality (VR) technology integrated with eye tracking to overcome this challenge. While eye-tracking technology alone can capture whether people attend to messages in their communication environment, most eye-tracking research is bound by laboratory-based screen-reading paradigms that are not representative of the broader communication environments in which messages are encountered. Emerging eye-tracking field research suffers from an inability to control and experimentally manipulate key variables. Our solution is to measure eye-tracking within an immersive environment in VR that resembles a realistic message reception context. Specifically, we simulate driving down a highway alongside which billboards are placed and use VR-integrated eye-tracking to measure whether the drivers look at individual billboard messages. This allows us to rigorously quantify the nexus between exposure and reception, and to link our measures to subsequent memory, i.e., whether messages were remembered, forgotten, or not even encoded. We further demonstrate that manipulating drivers' attention directly impacts gaze behavior and memory. We discuss the large potential of this paradigm to quantify exposure and message reception in realistic communication environments and the equally promising applications in new media contexts (e.g., the Metaverse).

Keywords: message effects, exposure, memory, recall, VR, eye-tracking, advertising, audience, retention, media analytics

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51 **Introduction**

52
53 Imagine driving down a seemingly never-ending highway, the billboard signs that line the road
54 occasionally catching your attention. You briefly glimpse at some, examine others more closely, and
55 completely bypass others. What will you remember when you reach your destination and why?

56 57 **Background**

58 *Exposure as the Cornerstone of Message Effects*

59 Exposure is the cornerstone of media and message effects. As the concept suggests, exposure is about
60 whether a message reaches a recipient, i.e., that the message enters a person's information environment
61 (1). This can include a sign along the road, a banner ad popping up while browsing the internet, or a
62 commercial interrupting a TV program. It is obvious that if audiences do not receive a message,
63 communication can not have any effect - just like a pill not swallowed cannot have any pharmacological
64 effects.

65 Given the central role of exposure as a prerequisite of any message effect, much research has focused
66 on measuring exposure. Virtually all media track information about audience sizes, such as newspaper
67 readership, website visitors and browsing behaviors, TV and radio audiences, and so forth. Very often
68 though, such data are only aggregate statistics, i.e., they provide information about average audience size
69 but not whether individuals received a particular message. This is the difference between opportunities for
70 exposure and actual exposure. Although conclusions based on exposure opportunities are possible (2),
71 they are still subject to criticism.

72 Despite this key limitation, the evidence relating exposure to message effects is strong. For instance,
73 opportunities for exposure (operationalized as how much a given message was "on air") are directly
74 related to the recognition of messages by target audiences (1,3,4). Similarly, several metrics of
75 commercial messaging success, such as brand awareness or ad recall, are directly related to the volume of
76 messaging, which is assumed to translate into exposure (5).

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78 ***Encoded Exposure and Incidental Memory***

79 To assess whether participants who might have been exposed to a message did actually receive it and
80 encoded it into memory, researchers typically ask them to remember the content of the message (6).
81 Different methods for probing memory exist, most notably free recall and recognition (7–9). In a free
82 recall task, participants are asked to recall information they remember being exposed to. In contrast, the
83 recognition method asks them to indicate whether or not an item was part of a set they encountered
84 previously. Recognition is typically higher than recall because not all existing memory traces are
85 retrieved during free recall.

86 Memory research has shown that multiple kinds of memory stores (e.g., explicit vs. implicit) exist and
87 that different encoding operations affect performance (e.g., whether participants encode items
88 superficially or more elaboratively) (10,11). The kind of memory most relevant to exposure research is
89 incidental memory, which is memory formed without the intention to memorize. This is actually the
90 default state we are in during much of our daily lives. Under such circumstances, attention is typically
91 deployed to items that are intrinsically salient or relevant, and the resulting incidental memories are most
92 relevant for message reception and effects research.

93 Although most of our memories are formed while we are engaged in everyday activities, most memory
94 research focuses on more deliberative memory tasks and studies memory formation under laboratory
95 conditions. This approach has led to important insights, but critics have long demanded that memory be
96 studied under more ecological conditions and that more focus be placed on everyday memory (12–14).
97 However, doing so requires overcoming obstacles that favor laboratory research and make naturalistic
98 memory research challenging. These include that it is exceedingly difficult to study peoples' behavior in
99 natural environments and the difficulty of manipulating experimental factors therein. This applies to
100 memory research in general, but also to research specifically focusing on memory for messages as it is
101 studied in communication and advertising (6,15–18).

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102 In sum, strong evidence underscores the importance of exposure for message effects. However, while
103 aggregate-level exposure data are consistent with a dose-response relationship between exposure and
104 recall, it is undoubtedly the level of a single exposure of an individual to a given message that causally
105 underlies these effects. Said differently, the actual exposure occurs not just when a given message is “in
106 the information environment”, but when it meets the eyes or ears of its recipients (1,19). However, not all
107 messages we are actually exposed to are remembered, and we know shockingly little about how many
108 messages we encounter in our daily lives. Therefore, there is a need to *close the measurement gap*
109 *between opportunities for exposure, actual exposure, and memory.*

110

111 ***Eye-tracking for Measuring Exposure: Strengths and Current Limitations***

112 Eye-tracking is an important tool for measuring visual information sampling (20). Eye tracking
113 provides direct information about where an individual is looking, which is in turn related to what
114 messages a person is paying attention to and how effectively they are processing the information. Due to
115 these desirable characteristics, eye tracking is actually widely used to study how individuals respond to
116 messages, where and for how they look, and so forth (21–24). However, one downside of previous eye-
117 tracking studies is that they were confined to controlled laboratory environments and most eye-tracking
118 was done using screen displays. While this approach is valid for studying how people browse internet
119 websites, it does not allow for eye-tracking studies in more natural environments, such as highways,
120 streets, and other contexts (25). As a result of this limitation, we know relatively much about situations in
121 which people are placed in front of screens to study which displayed messages they attend to, but very
122 little about more unconstrained information environments in which people freely initiate and terminate
123 exposure to messages. However, to the extent that these situations are the natural norm rather than the
124 exception, our knowledge and theories about exposure and its transmission into message effects are
125 woefully incomplete.

126 Recently, wearable eye-tracking technologies have been developed that enable researchers to study
127 message reception in natural contexts (25–27). While these technologies can overcome the limitations of

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128 screen-based eye tracking, they suffer the challenge of all field research, which is they don't afford the
129 experimenter to control the situation, offering limited potential for causal manipulation of variables that
130 are assumed to influence outcomes.

131

132 *VR's Virtues: Realism, Control, and Measurement Capability*

133 Virtual Reality (VR) can create a highly immersive and interactive experience, allowing researchers to
134 accurately simulate real-world environments and study human behavior in a controlled and systematic
135 manner. This potential of VR has been documented in various research contexts, including clinical
136 psychological research, communication and advertising, as well as memory and navigation research, to
137 name but a few (28–31). Key characteristics that recommend VR for research use include its realism, its
138 opportunities for experimental control, and its potential to integrate measurement (32). We will next
139 expand on each of these beneficial characteristics.

140 First, VR can create realistic environments that mimic real life - whether it is riding a rollercoaster,
141 walking along a virtual plank, or driving down a highway. Visual information is particularly central to the
142 human mind/brain and is one of the primary channels of human information intake that VR can virtually
143 simulate. Thus, researchers can design virtual environments that mimic the essential appearance of a wide
144 variety of human visual environments, and then explore the cognitive and socio-emotional mechanisms
145 generated in visual environments by VR.

146 Second, because VR environments are virtually created, they can be precisely controlled. For instance,
147 if the goal is to place a particular billboard along a virtual highway, researchers can create a virtual
148 highway model and place a virtual billboard along the roadside - no permit or construction costs are
149 required. This is obviously a great asset in terms of experimental control, which is widely seen as one of
150 the most critical features to experimentally demonstrate the causality of theoretical variables (mechanism
151 and intervention potential). Critically, however, in many situations, control is difficult and expensive to
152 achieve (e.g., permit, cost), sometimes even completely impossible. In this sense, the ability to virtually

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153 create and manipulate experimental situations offers researchers a unique tool that optimally balances
154 natural realism and experiment control.

155 Third, another desirable characteristic of VR is that it is relatively easy to integrate measurements for
156 behavioral research: Because the virtual environment a user enters is fundamentally digital, a lot of data
157 are naturally tracked as variables (e.g., a user's position in the environment, head orientation, speed of
158 movements). Additional variables can also be tracked (e.g., position of the hands). Currently, we see a
159 strong trend to incorporate bio-behavioral metrics into VR systems (e.g., hand- and facial tracking for
160 user interaction and avatar expressiveness, heart monitoring, eye-tracking, etc.) (33–35).

161 These three characteristics of VR - realism, control, and measurement potential - suggest it is an ideal
162 candidate for research on the exposure-reception-retention link, especially if paired with eye-tracking.
163 Indeed, some prior research has already used VR in this way. Many promising VR-related applications
164 are proposed for related research purposes, although we are not aware of direct applications focusing on
165 exposure to visual communication messages (33,36–40).

166 However, a fourth aspect should not go unnoticed. VR is heralded as the communication medium of the
167 future, i.e., as an emerging media channel rather than just a methodologically advantageous gimmick
168 (28,29,41,42). If true (see e.g., the rebranding of the social media company FaceBook to Meta), VR might
169 be on the way to becoming a messaging environment in and of itself. In other words, if people are going
170 to spend time in VR, they are exposed to a variety of messages while inside VR. Just like social media
171 metrics (e.g., likes, comments, page impressions, and viewable impressions) have enabled the quantitative
172 study of message diffusion on social networks, this development could also create opportunities to
173 connect data about quantified individual-level exposure (e.g., fixation to a message) to subsequent
174 outcomes.

175

176 The Current Study and Hypotheses

177 The current study examines how quantified exposure to messages in a realistic environment relates to
178 incidental memory of the messages. We introduce a novel VR billboard paradigm that simulates a drive

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179 down a realistic highway alongside which billboards are placed. Moreover, we combine this realistic and
180 controllable VR environment with eye-tracking, thereby leveraging the integrated measurement potential
181 of VR to capture exposure as it occurs.

182 To experimentally demonstrate the potential of this novel paradigm, we instructed half of the
183 participants to look out for trash placed alongside the highway. The other half was instructed to look
184 freely while driving down the highway. It is well documented that such a parallel, the attention-
185 consuming task will distract participants and should lead to fewer fixations to the billboard messages.

186 Beyond checking how the competing task affects fixations to the billboards, we were primarily
187 interested in whether looking at individual billboards would predict subsequent memory. The
188 abovementioned reasoning on the exposure-retention link predicts that messages that were looked at
189 should be committed to memory.

190 Finally, we wanted to explore general patterns of participants' viewing behavior in this situation. To
191 this end, we conducted additional data-driven analyses to identify patterns that would be predictive of
192 outcomes.

193

194

Methods

195 Participants

196 Forty participants ($m_{age} = 25.6$, $sd_{age} = 11.2$; 18 female) were recruited from a study pool and via word
197 of mouth. The local review board approved the study, all participants provided written informed consent
198 to the protocol, and student participants received course credit. The sample size was set *a priori* to 40
199 participants, which was chosen based on power considerations and prior work in basic memory and VR
200 research. Specifically, we determined that for an assumed large effect ($d = 1.2$), a sample size of 16 per
201 group would be sufficient for high power ($1-\beta = 0.95$, $\alpha = 0.05$) to detect a between-group difference in
202 the number of recalled billboards. We rounded this number up to 20 per group. One additional participant
203 whose goggles did not fit under the VR HMD was immediately replaced, resulting in a final sample of 40
204 participants.

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206 FIGURE 1 about here

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208 **Materials and Equipment**

209 *VR highway environment and billboard signs:* We developed a virtual highway in which 20 billboards
210 and additional highway-typical elements (construction signs, empty soda cans) were placed along the
211 road. The core highway model was downloaded from Sketchfab.com and consisted of a digitized 3D
212 model by the Nevada DOT (43). It featured a straight stretch of highway 50 taken near Cold Springs.
213 Virtual billboard signs were placed along the road using 3D-billboard model stands, and the billboard
214 messages were assigned to each of the 20 billboards stands in a programmatic fashion (randomized across
215 participants). The distance between successive billboards was assigned randomly and then kept fixed
216 across participants.

217 *Billboard messages:* We developed 20 visual billboard messages using templates from Canva.com. Half
218 of the billboards were about health-related topics (e.g., drinking, vaping, smoking, marijuana, seatbelt
219 use, and distracted driving). The second half of the billboards were typical advertisements (e.g., retail,
220 lawyer services, hotels, and restaurants/food). The billboard messages all featured basic imagery along
221 with some text, and their design was deliberately kept relatively simple but still typical of the kinds of
222 billboards present on US highways (see Fig. 1 and Supplementary Materials).

223 *VR and eye-tracking:* We relied on the Vizard VR software to create the VR environment, run the
224 study, and track user behavior, including eye-tracking measurements (Vizard, 7.0; (44)). The VR device
225 was an HP Reverb G2 Omnicept that includes eye-tracking capabilities. Participants used the right VR
226 controller to accelerate and drive forward along the virtual highway. Because the highway was perfectly
227 straight, no steering was required.

228

229 **Experimental Procedure and Conditions**

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230 Once participants arrived and consented to the study, they completed a quick vision test, put on the VR
231 headset, and underwent a calibration routine. Next, the participant entered a demo version of the study to
232 familiarize them with VR, the virtual space, and the navigation. Then, the main experimental session was
233 started, which involved driving down the virtual highway. Half of the participants were instructed to
234 count the number of trash items in the environment (distraction condition). The other half were told to
235 explore the environment while driving down the highway freely (free-viewing condition).

236 After completing their virtual drive (which took about 10 minutes), participants were given a set of
237 Sudoku puzzles for 2 minutes. Then, the experimenter conducted a structured interview that asked
238 participants about the number of trash items they saw, their general virtual driving experience, and which
239 billboards they recalled (free recall task). As the last step of the study, participants completed an online
240 questionnaire via Qualtrics that collected demographics, their experiences with the VR technology, and
241 recognition of billboards. Specifically, we asked participants to report on their experience of spatial
242 presence and the occurrence of symptoms while in VR (45); (46). For the recognition test, they were
243 shown the 20 experimental messages and four distractors and asked whether they remembered seeing the
244 messages during the highway drive. The purpose of the distractors was to gauge participants' tendency to
245 recognize all messages as seen. Finally, participants were debriefed, and their eye-tracking data was
246 saved.

247

248 Main Measures and Analysis Methods

249 The main variable measured during the virtual drive was participants' fixation on a given billboard,
250 which was detected algorithmically and saved to disk in a spreadsheet. The fixation threshold was set to
251 0.25s. Thus, for every participant, the virtual drive yielded a spreadsheet containing where a given banner
252 was fixated (and how often, e.g., time 15s, fixation, billboard_1, etc.).

253 Because billboard images were randomly assigned to individual billboard sign positions, a python
254 program was written to resort the individual images to a given participant's eye-tracking data (e.g., time

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255 15s, billboard_1, drunk_driving.jpg, ...), allowing for subsequent data aggregation across participants and
256 billboard messages.

257 The recall data (information on whether a participant brought up the billboard during the free recall
258 task, e.g., “I recall seeing a billboard about drunk driving”) was merged with the fixation information, and
259 so was the recognition data (information on whether a participant recognized the billboard at the end of
260 the study from a list of billboard images).

261 We document the analysis and provide code in the study’s online repository [link to data and scripts on
262 OSF and Github will be included in the final manuscript]

263

264

Results

265 We measured eye gaze while participants drove down a virtual highway with billboards alongside. One
266 group was instructed to pay close attention to trash, another group could explore the environment while
267 driving. Once they reached the end of the highway, we tested the participants’ incidental memory for the
268 billboard messages (they had not been told that they would be asked about the messages).

269 Participants' verbal comments about the study, collected during the verbal interview, revealed that they
270 found the virtual highway drive realistic and engaging. The post-experimental survey data confirms these
271 observations. Specifically, participants reported experiencing spatial presence in the VR environment
272 ($mean_{spatial\ presence} = 3.8$; range 1-5, i.e., all items above the scale midpoint). Participants also reported
273 almost no symptoms (e.g., dizziness, fatigue, or eyestrain; $mean_{VR-symptoms} = 1.36$, range 1- 4, i.e., all items
274 below the scale midpoint).

275

276 *Fixations as a Function of Load Condition and General Memory Performance*

277 To examine the effect of the experimental conditions (trash-counting vs. free-viewing), we compared
278 the number of fixations to billboards. As predicted, we find that participants in the free-viewing condition
279 had significantly more fixations on the billboards than participants in the trash-counting condition where
280 participants' attention was directed more to the road than the billboards ($mean_{fixations:free-viewing} = 52.8$, $sd =$

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281 22.9; $mean_{fixations:trash-counting} = 21.8^1$, $sd = 16.1$; $t_{38} = 4.98$, $p < 0.001$; $d = 1.58$). These results are shown
282 graphically in Fig. 2 (left panel).

283 Next, we examined the memory performance collected in the interview. In the free recall test,
284 participants in the free-viewing condition recalled an average of 6.45 billboards ($sd = 1.57$, $recall_rate_{free-}$
285 $viewing = 0.32$, significantly more than the average 2.95 ($sd = 1.76$, $recall_rate_{trash-counting} = 0.15$) billboards
286 the participants in the trash-counting condition recalled ($t_{38} = 6.63$; $p < 0.001$; $d = 2.1$; see Fig. 2, middle
287 panel).

288 Carrying out the same analysis on recognition data revealed even more pronounced results: Participants
289 in the free-viewing condition recognized on average 14.6 billboards ($sd = 3.25$; $recognition_rate_{free-viewing}$
290 $= 0.73$) compared to only 7.1 billboards recognized in the trash-counting condition ($sd = 3.68$;
291 $recognition_rate_{trash-counting} = 0.35$), which is a highly significant difference ($t_{38} = 6.78$, $p < 0.001$, $d = 2.14$,
292 see Fig. 2, right panel).

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294 FIGURE 2 about here

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296 ***Relationship between Fixations (Exposure and Attention) and Memory***

297 Next, we focused on the relationship between fixations on individual billboards and subsequent
298 memory for the billboards. Toward this end, we determined for every participant the number of looked-at
299 billboards (i.e., fixated at least once) that were later recalled (or recognized) and the corresponding
300 number of billboards that were not-looked-at (i.e., never fixated). The resulting table was then submitted
301 to an ANOVA, which revealed highly significant and consistent effects for both ways of assessing
302 memory.

¹ Based on this average it is tempting to assume that all participants in the trash-count condition may have looked about once at every billboard (20 in total). However, this was not the case. Rather, a few participants looked at some billboards more often, and many participants in the trash-counting condition did not look explicitly at many billboards.

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303 For free recall, there was a highly significant interaction effect between condition and fixation status (F
304 $_{(1,38)} = 25, p < 0.001, \eta^2_p = 0.4$) and a highly significant main effect of fixation status ($F_{(1,38)} = 132.6, p <$
305 $0.001, \eta^2_p = 0.78$). Follow-up tests confirmed higher recall in the free-viewing condition.

306 The results for the recognition data closely resembled the recall analysis: A highly significant main
307 effect of fixation status ($F_{(1,38)} = 91.2, p < 0.001, \eta^2_p = 0.71$) was qualified by a significant ordinal
308 interaction of condition and fixation status ($F_{(1,38)} = 23.5, p < 0.001, \eta^2_p = 0.38$). Follow-up tests again
309 confirmed that recognition memory was higher in the free-viewing condition compared to the trash-
310 counting condition. In other words, we find that if a billboard is looked at at least once, this boosts the
311 likelihood it will be remembered by a factor of 5-20 (depending on the condition and how memory is
312 measured).

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314 FIGURE 3 about here

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316 To illustrate this more clearly, we created a Fig. that jointly visualizes whether a billboard was looked
317 at and whether it was recalled or recognized, respectively, and in which condition (see Figs. 3 & 4). As
318 can be seen, in the trash-counting condition (blue dots), many billboards are not looked at at all. In the
319 free-viewing condition (orange dots), more billboards are looked at (see results in the previous
320 paragraph). Critically, however, the billboards that are never looked at are practically never recalled (top
321 left quadrant in the scatter plots, see discussion for explanation). The banners that were looked at (right
322 column), are far more often recalled, and almost always recognized.

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324 FIGURE 4 about here

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326 To examine this strong contingency between looking and remembering at a more fine-grained level, we
327 further unpacked the fixation data. Specifically, we extracted for every participant whether a billboard
328 was never looked at, looked at a few times (i.e., at least once but less than that participant's medium

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329 fixation count across all 20 billboards), or looked at often (more than that participant's medium fixation
330 count across all 20 billboards). The results of this analysis are illustrated in Fig. 5, and they are
331 statistically significant. A repeated measures ANOVA for the average number of items recalled (DV)
332 revealed a strong effect of Viewing Behavior Intensity ($F_{(2,76)} = 12.1, p < 0.001, \eta^2_p = 0.24$) with a
333 significant interaction of Viewing Intensity * Condition ($F_{(1,38)} = 3.68, p < 0.05, \eta^2_p = 0.09$).

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335 FIGURE 5 about here

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337 *Exploratory Analyses*

338 The approach presented here affords predictive modeling. To this end, we used scikit-learn (47) to
339 create a model that could classify whether a billboard would be recalled or not based on the existing
340 variables, i.e., which billboard was presented (e.g., buckle-up, drunk_driving, hotel, etc.), how often the
341 participant fixated it, in which position the item was viewed, and the condition (trash-counting vs. free-
342 viewing). Using a 5-fold cross-validated SVC prediction, we found that this simple model performed
343 well, with a ROC-AUC score of 72.8% - compared to 50% for a dummy classifier (note that we used
344 penalization to deal with the imbalance classes, i.e., recall being rarer than no recall). Said differently,
345 once we know that a participant looked at a given billboard, we can predict more accurately whether this
346 participant will later recall it. This relationship can also be derived from the statistically significant effects
347 and the data shown in Figures 3-5.

348 In addition to statistical testing and predictive models, we carried out additional analyses to examine
349 false recognition, results for individual participants and individual billboards, effects of item position, and
350 health vs. commercial billboard content.

351 To gauge the degree to which participants would be prone to false recognition, we included distractor
352 billboards in the recognition set (i.e., billboards that were never seen). However, these distractors were
353 only rarely falsely recognized, significantly less than all presented billboards, and only one participant

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354 mis-recognized more than two distractor billboards. Thus, even though recognition measures can be prone
355 to guessing, this does not seem to be the case here.

356 We also explored the relationship between fixations and memory and between different memory
357 measures at the individual level: In the trash-counting condition, the number of fixations and memory
358 measures were highly correlated (r values > 0.7 , p values < 0.001), suggesting that participants who were
359 more interested in the billboards or the study also remembered them better. In the free-viewing condition,
360 this was not the case (r values were nominally even negative). In both conditions, however, recall and
361 recognition were positively correlated ($r = .54$, $p < 0.001$ for the trash-counting condition, $r = 0.2$, $n.s.$, for
362 the free-viewing condition). While these results are interesting and point to effects of motivation or
363 interest, we opted not to investigate them further because the current sample was relatively small for
364 studying individual differences.

365 Moreover, we inspected the potential influence of the billboards' position (beginning vs. middle vs.
366 end) on the probability of fixation, recall, or recognition. However, we did not find such effects, nor
367 evidence of an interaction with the condition. In both conditions, position curves were parallel and flat.

368 Inspection of the results for individual billboards, however, revealed interesting effects: Specifically, as
369 shown in Fig. 6, some items were often recalled (e.g., buckle_up, disobey_vape, and burger) - others were
370 barely remembered. This is also consistent with the predictive modeling result, where adding the item
371 (one-hot-encoded) as a feature increased accuracy. Most likely, this is due to intrinsic differences between
372 the billboards - either because of the topic's relevance to participants or because of low-level physical
373 differences, such as saliency. Of note, we did quantify perceptual saliency (48) but did not see a
374 significant relationship with memorability.

375 Lastly, we also compared the health-related banners against the commercial banners, finding no
376 significant differences. Nominally, health-related billboards were slightly more often recalled (also see
377 Fig. 6), but the effect was insignificant ($F_{(1,36)} = 3.53$, $p = 0.07$). Across both conditions (independent
378 participants), the same billboards tended to be recalled more often, as indicated by a significant vector
379 correlation between trash-counting and free-viewing ($r = 0.82$, $p < 0.001$).

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381 FIGURE 6 about here

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383 **Discussion**

384 Messages are intended to inform and influence recipients. However, this requires that they are viewed,
385 i.e., that audience members are actually exposed to the message. Therefore, exposure is the cornerstone of
386 all message effects, but measuring exposure is challenging - especially at the individual level and within
387 realistic messaging contexts. Here we created a VR paradigm that immerses users in a realistic
388 environment familiar to many: a drive down a highway with billboard signs along the road. Using a VR-
389 integrated eye-tracker, we recorded whether participants looked at individual billboards and we link this
390 information to subsequent memory for the billboards. Our results show that this approach allows us to
391 rigorously assess the exposure-reception-retention nexus.

392

393 **Discussion of Main Results**

394 The current results are very clear and straightforward: The VR Billboard Paradigm enables studying
395 whether people look at (i.e., take in the information) from the messages they were exposed to. As simple
396 as this sounds, the significance of it becomes apparent if one considers that exposure is the cornerstone of
397 message effects, but exposure is often only inferred rather than actually measured (i.e., how often a TV ad
398 is on air and typical audience sizes are taken as opportunities for exposure). Clearly, these indirect ways
399 of assessing exposure miss the point because what really matters for message effects is *actual reception*,
400 not *fiat exposure* (“Let’s hope people will look at the message”). Our paradigm now makes it possible to
401 study this and to do so in a way that strikes a balance between realism and experimental control.

402 Perhaps the most important effect is that participants’ viewing behavior was significantly associated
403 with message memory: Technically, one could have argued that all participants passed by all messages
404 (i.e., had the opportunity for exposure). However, measuring their visual information sampling via eye

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405 tracking made it possible to measure actual exposure - and thus reception -, and this explained whether
406 billboards would be recalled.

407 A third point was the strong influence of the task: Participants who were instructed to drive freely
408 looked at the billboards more often and they recalled them more often. By contrast, participants who were
409 instructed to count trash along the road showed very few fixations towards the billboards and generally
410 low memory. Again, this perfectly matches our predictions that participants' attention would be
411 consumed by the task, as it is well-known that attention and memory are tightly coupled (49–52).

412 These results all support our main argument, which is that exposure and reception are the prerequisites
413 of message retention (memory). The present approach thus has value for pinpointing the mechanism that
414 leads from exposure to retention: Specifically, the causal chain starts with the presence of a message in
415 the information environment (opportunity for exposure), then the person noticing and taking in the
416 message (actual exposure, reception), to subsequent memory (retention). Further evidence for this causal
417 pathway is also provided by the dose-response relationship, i.e., the marked differences between fixations
418 and memory in the trash-counting vs. free-viewing conditions, and by the fact that messages that were
419 looked at more were recalled more often.

420

421 Broader Implications

422 The new approach presented here holds significant value for understanding exposure and reception as
423 the critical nexus between message and receiver in communication. As such, the approach is not only
424 methodologically intriguing but also promises to advance our understanding of the theoretical factors that
425 affect the exposure-reception-retention nexus.

426 Although in communication science the concept of exposure has remained hard to study naturalistically,
427 experimental memory research is an area in which exposure has always been manipulated - by forcing
428 participants to attend to messages and then study the effects on memory. As such, laboratory work on
429 memory encoding and work flowing from incidental and ecological memory perspectives is
430 complementary to the current approach (52,53), although our emphasis differs by taking a communication

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431 perspective (3). For instance, in memory research, the levels of processing framework highlighted how
432 recall of memoranda varies based on processing depth (10,54). The core assumption is that the mental
433 operations carried out over items (e.g., whether they are processed semantically or only superficially)
434 influence the probability of recall. Such work has also found its way into communication science, for
435 instance via the popular elaboration-likelihood-model and related work (55,56). Likewise, the concept of
436 involvement in advertising has been proposed to refer to the degree of personal connections message
437 recipients make with a message once they received it (57). Finally, the notion of exposure states also
438 points to the importance of examining the psychological processes message recipients engage in once
439 they are exposed to messages (19). Thus, these different models and theories all have in common that
440 they require measuring i) whether messages are received and ii) how people engage with them. The VR
441 billboard paradigm presented here can definitely ascertain the former (whether messages are seen). To the
442 extent that fixation amount and length can give insight into the latter (how messages are engaged with),
443 we can also examine this with the current paradigm. Moreover, the paradigm can easily be expanded to
444 measures like pupil dilation (or derivative metrics like fixation length, paths, etc.). In sum, the VR
445 billboard paradigm resolves a longstanding problem in a new way that promotes method-theory synergy
446 (58) between VR and eye-tracking research, laboratory, and everyday memory, and work on the
447 exposure-reception-retention nexus in communication.

448 Beyond these theoretical considerations, this approach clearly has significant applied potential as well:
449 First, the VR billboard paradigm is directly applicable to billboard advertising in the real world. For
450 instance, it could be immediately used to empirically examine the effects of new constructions on existing
451 billboards (e.g., as legal testimony), forecast billboard effectiveness, and so forth. Second, the approach
452 can easily be adapted to other applied messaging questions because many message delivery contexts
453 could be implemented in an equivalent manner. These include all forms of outdoor advertising, including
454 airports, public transportation, and public spaces like Times Square in New York, the strip in Las Vegas,
455 or any place where large audiences pass by. In all of these cases, the ability to experimentally manipulate

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456 key characteristics of the appearance or the users' state and assess the effects of such manipulations on
457 quantified user behavior (here, eye-tracking) could be of major value.

458 We note that we are not the first to point to the potential of VR and eye-tracking for studying exposure
459 and memory and that several related works exist. For instance, Kim et al. (59) have suggested a 360-
460 degree video paradigm for measuring viewing behavior in naturalistic settings (i.e., 360-degree videos of
461 real cityscapes). This approach combines realism and eye-tracking. From an experimental point of view,
462 however, the ability to control the placement and content of billboards, or even make message delivery
463 contingent on behavior, offers key strengths and innovations.

464 Going forward, we also expect key advances by integrating additional measures beyond the current eye-
465 tracking. For instance, our results here focus on the eye gaze fixations and make hardly any use of pupil
466 dilation or heart rate, both of which are already integrated into the HP Reverb G2 Omnicept headset. Kim
467 et al. (59), for instance, did combine their video with MRI measurement. Although VR is challenging to
468 combine with MRI (because the equipment is not compatible with brain scanners and head motion
469 presents problems for MRI), other options exist and will likely become more widespread. These include
470 EEG and fNIRS, which can provide additional insights into, e.g., the neural basis of memory formation
471 and attention (51,60,61). We also note that there were very few messages that were not looked at, but
472 were still remembered (very rarely recalled freely, but sometimes recognized, see Fig. 4). This can be
473 explained by parafoveal or ultra-fast vision (i.e., below fixation threshold, 62-64) and one could argue
474 that these events are rare. Still, in such a case, neural measurements could add in information beyond eye
475 tracking alone.

476

477 Strengths, Limitations, and Avenues for Future Research.

478 Key strengths of the VR billboard paradigm include that it is simple, realistic, flexible, and scalable.
479 Using VR in combination with eye-tracking to study message reception is not confined to billboards on
480 highways, however, but could be applied to other settings. It would, for instance, be very simple to

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481 exchange the environment and use the same available python code to detect fixations on messages in e.g.
482 city settings.

483 Perhaps the biggest advantage of this approach over existing work (either screen-based eye-tracking or
484 eye-tracking field research) is that it allows for the controlled testing of causal mechanisms, while
485 preserving a high degree of realism. The ability to measure precisely and objectively and to control
486 variables experimentally are the key prerequisites for causal mechanism identification in, e.g., the
487 biological and behavioral sciences. In the social sciences, which often rely on macro-level association
488 data, these features are difficult to achieve. In this sense, the current paradigm holds great potential to
489 overcome many limitations that have plagued message exposure research. Of note, though not the main
490 focus of our study, this paradigm would seem equally promising for applied memory research (52,53).

491 Like all research, the current study has several limitations. One limitation is that although the VR
492 experience featured a realistic version of a real highway drive (a digital twin of highway 50 near Cold
493 Springs), some elements of real life were missing (e.g., opposing traffic, birds, curves, and passages
494 through towns, etc.). Likewise, our experimental messages are also limited in variety, number, or design-
495 and content elements. We deliberately made these choices to balance experimental control and realism,
496 but it could of course be argued that specific features might matter. Fortunately, it is easy to add and test
497 such factors, and high-realism driving games demonstrate that this is feasible (e.g., the popular Need for
498 Speed or GTA series).

499 Another limitation concerns the mostly student sample and its size. While our sample was adequate for
500 the study's goal, which was to demonstrate the value of this new paradigm by eliciting a fairly basic
501 memory effect, future studies examining smaller or more contextual effects will require larger and more
502 diverse samples. Given that most VR research is still conducted in laboratory settings and measuring one
503 person at a time, this will lead to a bottleneck at the data acquisition stage. However, as VR enters the
504 mass market, we can expect that VR crowd studies will emerge. This would then provide researchers with
505 access to samples the size we see in survey research, but with the added opportunity to capture
506 biobehavioral data during message reception.

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507 Considering the above-mentioned strengths and limitations, we regard the following avenues for future
508 research as promising: First, it would be promising to extend the context from billboards along highways
509 to broader messaging contexts, like cityscapes, airports, and so on. All of these situations can be created
510 virtually with little effort, and several free 3D models do exist. Similarly, even the current VR billboard
511 paradigm offers a host of options. For instance, it would be promising to examine the influence of
512 distractions or contexts, such as concurrent radio messages along the drive, or manipulations of user-state
513 variables (like having hungry participants view food billboards; (65)).

514 Along these lines, we also see much potential for more dynamic manipulations. By this, we mean that
515 the current study only manipulated static billboards and the messages that were shown along a virtual
516 drive. The next step would be introducing manipulations in which the messages are contingently
517 administered. For instance, it would be possible to show a message if the driver previously looked at
518 another one or to show a message for as long as needed until the driver viewed it. These options show the
519 enormous potential for persuasion and nudging strategies, which are of course a double-edged sword: On
520 the one hand, these could be leveraged to improve the effectiveness of health communication. On the
521 other hand, they could be used for commercial advertising. Regardless of the intent of the messenger,
522 however, it is undoubtedly the case that such applications would bring communicators closer to the long-
523 standing goal of being able to “give the right message to the right recipient, at the right moment in time.”

524

525 Summary and Conclusion

526 In sum, we suggest a new paradigm to study the link between attention and retention, or exposure and
527 memory for messages. The VR billboard eye-tracking paradigm allows for studying incidental memory
528 formation under highly realistic conditions, but with exquisite experimental control and integrated bio-
529 behavioral measurements. The result that fixations are related to memory confirms the link between
530 exposure/attention and retention/memory, underscoring the potential for this paradigm to study memory
531 in real-world contexts and communication effects in the new information ecosystem.

532

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660

661 **Figure Captions**

662 **Fig. 1.** Overview of the experimental protocol. Top row: Screenshots of participant and experimenter
663 views with one example billboard ('drunk_driving'). Bottom left: Experimental timeline and conditions.
664 Half of the sample was instructed to count trash along the road, the other half was instructed to simply
665 drive down the highway. Except for this difference in instruction, the highway and billboards were
666 identical for both conditions. Bottom right: Participant wearing an HP Reverb G2 Omnicept VR headset.

667

668 **Fig. 2.** Number of fixations, free recall, and recognition rates by condition.

669

670 **Fig. 3.** Relationship between fixations and subsequent message memory. Probability of recall (left) and
671 recognition (right), based on whether a billboard was looked at (not fixated or fixated at least once) and
672 condition (count trash vs. free viewing).

673

674 **Fig. 4.** Relationship between fixations and subsequent message memory at the level of single messages.
675 Left panel: Fixations and free recall performance. Every dot represents one billboard, color-coded based
676 on whether participants were instructed to count trash (distraction) or view freely. Note that dichotomous
677 variables (0 - not looked at/not recalled, 1- looked at/recalled) were jittered randomly to aid
678 visualization. Right panel: Same analysis but based on a recognition memory test.

679

680 **Fig. 5.** Relationship between Viewing Behavior Intensity and Message Recall at a more refined level (i.e.,
681 beyond looking vs. no-looking).

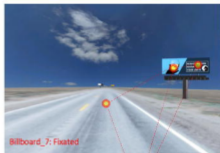
682

683 **Fig. 6.** Analysis for individual billboards. Across both conditions (independent participants), the same
684 billboards tended to be recalled more often.

First-Person View:
Highway with Billboards



Experimenter View:
Highway with Billboards and Gaze Data



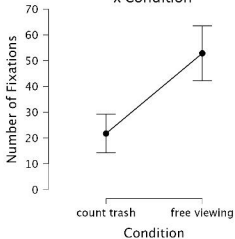
Experimental Timeline
and Conditions



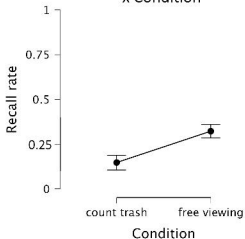
Participant wearing VR Headset
with Eye-Tracking-Integration



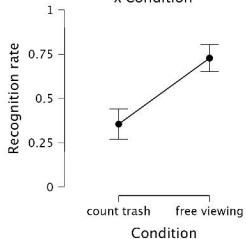
Fixation Count
x Condition

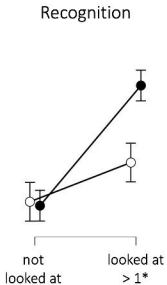
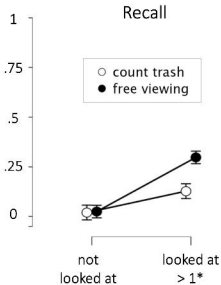


Recall Rate
x Condition

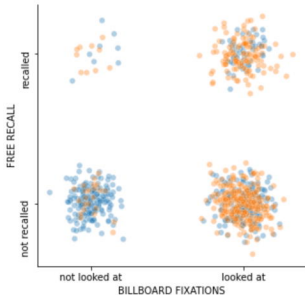


Recognition Rate
x Condition





Fixation → Free Recall



Fixation → Recognition

