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Research Article

Eyes on VR: Unpacking the Causal Chain Between Exposure, Reception, and Retention for Emotional Billboard Messages

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The causal chain from message exposure to reception to effects is widely accepted as the basic explanatory model for communication and message effects. However, the chain's links were often studied in isolation, leaving measurement gaps that compromise the ecological validity and practical utility of experimental research. Here, we introduce a VR-based paradigm that encompasses a realistic message reception context, that is, a simulated car ride on a highway flanked by billboards. We varied emotional salience as the core message factor as well as contextual distractions. VR-integrated eye trackers were used to capture participants' incidental and self-determined message exposure dependent on their actual gaze behavior. Consistent with our predictions, results show that (1) exposure gates all subsequent effects, (2) distraction impacts the likelihood of exposure, and (3) both the manipulation of emotional content and distraction affect retention. This comprehensive research ecosystem for assaying the exposure–reception–retention chain can be broadly applied to a variety of message reception contexts.

Keywords: emotional salience; exposure; memory; message effects; reception; virtual reality

1. Introduction

Humans encounter a deluge of messages daily, but amidst continual opportunities for exposure, many messages are ignored, some receive closer attention, and few are retained in memory (e.g., [1]). For instance, consider the myriad billboards people pass by during routine commutes. Which ones are people paying attention to, and which ones stick in their memory? What factors contribute to this? Does memory for certain messages depend on observers' state of attention while passing the billboard or on features inherent within the message, such as more or less emotionally salient image content?

While encountering a multitude of visual messages, people are typically free to look at or ignore the messages. Exposure to messages [2], that is, the contact between the message and the recipient, depends on selective visual attention. Thus, all message effects hinge on whether individuals even look at a message, and messages that are not even attended to cannot have any influence. However, despite the significance of exposure for communication, our understanding of its role in real-world contexts remains somewhat limited. For example, we still lack answers to many basic questions, such as how many messages a typical individual encounters on a normal day or what fraction thereof they attend to or ignore. Progress in screen-based analyses [3] can offer such estimates for computer-mediated messages, but a measurement gap persists for natural communication contexts in which messages are embedded in complex environments with competing attentional demands and where message exposure is incidental and depending on people's idiosyncratic behaviors. Moreover, while measuring exposure is crucial for understanding message effects, it is also only a necessary first step, and ultimate message effects depend on further processing steps related to how we engage with messages and how we store them in memory [4]. This paper examines these fundamental questions for mass communication and media effects theories, with significant practical implications for health and political communication as well as advertising.

The paper is structured as follows. First, we introduce the causal chain from exposure to reception to retention, discussing how overt attention converts exposure opportunities (messages floating in one's environment) into actual reception (messages that are looked at and inspected) and how paying attention to messages facilitates subsequent retention (memory). Second, we discuss how previous research is generally compatible with this model but suffers from gaps regarding quantifying exposure in a rigorous manner while striking a balance between experimental control and realism. The current study uses virtual reality (VR) to create a messaging context (a drive down a highway with billboard messages alongside), employs eye tracking to quantify the exposure-reception nexus, and manipulates both the presented billboards' emotional content and the drivers' attentional resources to demonstrate the hypothesized links among these theoretical variables.

1.1. Attention and the Causal Chain From Exposure to Reception to Retention. Attention is a fundamental bridging construct between mass communication (focusing on messages in the external information environment) and psychology (focusing on the encoding and processing of those messages inside the neurocognitive system; [5–8]). Broadly defined, attention refers to the cognitive process of selectively focusing on a particular aspect of information [9, 10]. However, rather than treating attention as a unitary theoretical concept, we can distinguish various subtypes based on the setting, task, or other characteristics [11].

In the context of visual information environments, such as billboards along a highway, the first kind of attention is overt visual attention [12]. Overt attention refers to the fact that one can attend to (look at) aspects of the field of view, for instance, by fixating on a billboard while averting gaze—at least for a moment—from the road. This kind of attention is thought to function as a gatekeeper for all subsequent message effects. Understood this way, the act of attending overtly to a message links exposure to reception [7], which is what we turn to next.

However, even when we overtly look at information, as in reading this sentence, we can process it in a more focused or more superficial manner [13, 14]. Thus, even when exposure is sure, there is a secondary kind of attentional selectivity, that is, how long or how deeply we engage with content (e.g., [15]). There is evidence that links this kind of attention to memory (e.g., [16, 17]).

Although the literature on visual attention is vast and multiple theories feature varieties of attention and their effects (e.g., [11]), two generalizations can be made regarding the modulators of attention: message characteristics and task demands. First, regarding the message characteristics, messages that are salient or conspicuous attract and sustain attention [18]. Salience can be defined narrowly via features like brightness, contrast, or sudden onset; these lower-level attributes also explain a large share of eye movements and thus overt visual attention [19]. However, above and beyond lower-level attributes, higher-level attributes like emotionally salient content can also modulate attention. For example, pictures of cute babies, threatening or scary images, or explicit content all tend to capture and hold visual attention [20–22]. Applying this to the driving context, more emotionally salient billboards might attract attention more powerfully than less emotionally salient billboards, and there is indeed evidence that drivers passing by accident sites exhibit 'attentional rubbernecking' effects driven by emotional salience (e.g., [23]). Extensive research on emotional image processing shows a link between emotionality, attention, and memory [24, 25], although this is mainly demonstrated for highly salient image content, less so for the more delicate touches of emotion we see in daily media messages.

Second, regarding task demands, it is well known that when attention is focused on one task, the performance on another task can suffer (e.g., [26, 27]). For instance, when we are looking out for something in particular, we may fail to notice even very obvious and large objects [28]. In typical experimental contexts, we can steer participants' attention by instructing them to look out for and count particular target items [29]. This can also be applied to the context of driving, where one primarily focuses on driving, but other items may compete for attentional resources [30].

1.2. The Memory Trace: What Sticks After Exposure and Processing and How Attention Might Boost Retention. Summarizing the above, we argue that the links of the causal chain go from exposure to reception and to retention (e.g., [4, 31]). Clearly, visual attention is essential for turning exposure opportunities (messages one could look at) into reception—making sure that they are encoded in the first place. However, attention also refers to how intensely people engage with messages during the postexposure reception process, thus affecting how they are encoded (e.g., [27, 32]). Furthermore, we know that emotional messages may attract and hold attention better, and we know that distraction interferes with or depletes attention. All these variables should thus affect the chance of retention in a predictable manner: First, only exposed messages have a chance to make it into memory. However, not all messages we see and process can be stored verbatim. Thus, more emotional messages should command more attention and generally facilitate memory formation. Finally, attentional distraction should reduce exposure likelihood and dampen subsequent processing, thus lowering the likelihood of remembering a message.

1.3. The Challenge of Examining This Exposure–Reception–Retention Pathway. This theoretical chain from exposure to reception to effects is a logical and generally accepted explanatory model across communication. The processes described above (overt attention, selective attention, and memory encoding and retrieval) have been intensively studied in both cognitive psychology and neuroscience [33]. Moreover, work on the processing of media messages is also compatible with this reasoning [27], and so is McGuire's classic matrix of persuasion [4] or models in advertising research (e.g., [34]) and audience studies [14].

However, while important prior research has provided valuable insights into individual aspects of this pathway from messages to attention to retention—the metaphorical links in the chain—we still lack a cohesive experimental framework that would allow studying the entire process comprehensively and with an emphasis on realism. Developing such a framework is a key contribution of this manuscript. With this in mind, we note that prior work differs in important ways from the current experimental context (billboards along a visually realistic highway), particularly regarding stimuli, tasks, and external validity. First, laboratory studies in experimental cognitive psychology and neuroscience often bear little resemblance to the more natural phenomena they were designed to study, particularly not to everyday messaging contexts (e.g., [35]). Second, while prior work on mediated messages and dynamic information acquisition aligns exceptionally well with the information processing view presented above, such work has typically focused only on temporal media messages (e.g., TV and radio spots; [27, 36, 37]). Moreover, work on the reception of messages has been mostly done in laboratory tasks in which participants are force-exposed to messages. Thus, this work provides insights into postexposure processing but not into the exposure–reception link. Said differently, studying the exposure–reception–retention chain requires an approach that lets people search for information more actively while they are immersed in more realistic environments. The VR billboard paradigm introduced below was designed to help with this.

Also, research about message exposure does exist (e.g., [2]), but it is rather disconnected from work that is more focused on media reception (e.g., [27, 36]). Specifically, in mass communication and media effects research, exposure is a core theoretical concept [38], and dozens of metrics try to determine how many people are exposed to messages (audience size, reach, or frequency of messaging). However, the majority of this work on exposure regards aggregate-level exposure metrics but not whether a given individual looks at a message and how that influences the individual [39].

In summary, despite the fundamental importance and wide acceptance of the exposure–reception–retention chain, it is somewhat surprising that these links are often studied separately. Although important work has been done to characterize both the effects of exposure (e.g., [2]) as well as the minutiae of message reception processes (e.g., [40, 41]), there remain two key research gaps. First, there is a micro–macro divide, referring to the fact that exposure statistics are often used in research, but what really counts is the microlevel information intake by single individuals. This is rarely studied. Second, there is a gap between the real world of 3D visual information environments (where people are free to look around) and laboratory studies on message reception (where people are instructed to look at the screen).

1.4. Combining VR and Eye Tracking to Examine the Exposure–Reception–Retention Chain. Eye-tracking technology combined with VR presents a promising innovation that advances theoretical progress by enabling communication researchers to effectively dissect the exposure–reception–retention chain (e.g., [42]). First, because eye-tracking measures directly where people look and for how long their gaze stays engaged, it provides objective information about exposure and represents a widely accepted measure of visual attention [43]. Second, VR offers a promising way to overcome the limitations of laboratory studies, especially their limited realism. Specifically, as its name suggests, VR provides a way to create virtual but realistic environments. The implications of this feature become clear if one considers the challenge of measuring real-world exposure discussed above. Typically, we cannot objectively know whether a person looks at a billboard when driving down a highway because we neither have eye-tracking information nor can we manipulate experimentally which messages appear along a highway. On the other hand, experimental research often suffers from limited generalizability, particularly when done in restricted laboratory contexts (e.g., [44]). With VR, it becomes possible to overcome this bottleneck by creating realistic communication environments (e.g., a road with billboards, a mall, or a city; [45]). Because recent VR devices have integrated eye-tracking, it becomes possible to combine the potential of creating realistic communication environments in which users behave naturally with the benefits of measuring eye-tracking. Finally, VR-based experimentation allows to isolate and manipulate theorized variables (like the influence of message emotionality or distraction) while controlling confounds. This is a key prerequisite for establishing a causal chain and achieving strong inference [46, 47].

Recent research has already made some progress towards these goals. Specifically, Bonneterre et al. [48] and Schmälzle et al. [49] both used the same core idea—combining immersive VR with eye-tracking—to zoom in on the exposure–reception link and study it under controlled but realistic conditions. The former authors studied the reception of tobacco-related messages in the city environment and demonstrated that incidental exposure can be studied and linked to memory outcomes and smoking-related attitudes. The latter authors introduced a VR-billboard paradigm developed around a highway-driving scenario and demonstrated the key role of incidental exposure as well as how driver distraction makes it more or less likely. This study builds on this prior work to take it to the next level by manipulating multiple variables related to attention—message emotionality and distraction.

1.5. The Current Study and Hypotheses. The current study tests the above-described theoretical framework in which reception is the central link in the causal chain from exposure to memory, with attention serving as a key modulator of both the exposure-to-reception and the reception-to-memory linkages. Examining this framework in a causal-experimental fashion is enabled by an innovative experimental–ecological approach. Specifically, we build on previous work [49] that combined VR technology with integrated eye-tracking to create a message reception context in which people are free to attend to or ignore messages they encounter (driving down a highway with billboards) while allowing us to rigorously manipulate variables, capture eye movements, and examine how these factors affect incidental message exposure and subsequent retention.

With this approach, we conceived the following manipulations to influence attention (see Figure 1). First, we manipulated the emotional salience of the messages that participants encountered. Specifically, we created different versions of the same billboard message—varying only the level of the depicted images' emotional salience (low vs. high) while keeping other visual and textual features highly consistent. Participants were unaware of these variations, as every person encountered a mix of emotional billboards during a virtual ride down a highway, but behind the scenes, one participant would encounter the low emotional version of one and the high emotional version of another billboard, whereas another participant would receive exactly the opposite pattern, thus controlling for confounds.

Second, we instructed participants to either look out for and count trash items along the road (trash-counting condition) or freely drive down the road (free-viewing condition). This was done with the assumption that the distracting and demanding trash-counting task should markedly affect how much participants would attend to billboards and in turn impact their memory. During the ride, we then used the VR-integrated eye-tracking to unobtrusively measure whether they attended to each billboard (i.e., overt visual attention) and for how long they looked at it (i.e., intensity). Finally, once participants arrived at their virtual destination, we assessed their memory of the messages via an unannounced free recall task as well as a recognition test. With this setup, we are thus able to isolate the effects of billboard emotional salience (i.e., low vs. high emotional visual content) and driving condition (i.e., trash-counting vs. free-viewing) on visual attention and memory, combining high levels of experimental control with ecological validity.

Based on the theorizing presented above, we predicted that the emotional saliency of the billboards would impact visual attention. Specifically, we predicted more fixations (H1a) and longer gaze durations (H1b) towards the more emotionally salient billboards compared to the less salient counterparts. Moving from attention to billboards to their retention in memory, we predicted a similar effect of the emotional salience of billboards on retention, such that more emotional billboard messages will be better recalled (H2a) and recognized (H2b) than less emotional messages.

Aside from manipulating the billboards' emotional salience, we also manipulated whether participants drove down the VR highway freely (free-viewing) or whether they looked out for and counted trash (trash-counting). Specifically, we expected that individuals in the free-viewing driving condition would exhibit more fixations (H3a) and longer gaze durations (H3b) compared to those in the trash-counting driving condition. And lastly, we predicted the strong effects of this driving condition on billboard retention, such that individuals in the free-viewing driving condition would exhibit better memory performance (H4a—measured via recall; H4b—measured via recognition) than those in the trash-counting driving condition.

2. Method

We provide code and data in a reproducibility package at [https://github.com/nomcomm/vr_billboard_e]. In brief, participants wore a VR headset with integrated eye-tracking and drove down a photorealistic (virtual) highway along which billboard messages were placed (see Figure 1). Depending on the condition, they were instructed to count trash placed along the road or drive freely, and the displayed billboards were manipulated as described below. After the drive, participants' incidental memory of the billboards was assessed via a free recall and recognition task. In the following, we report the specifics of the sample and procedures.

2.1. Participants. Forty participants ($m_{age} = 20.2$, $SD_{age} = 1.5$; 24 female) were recruited and received course credit. The study was approved by the local Institutional Review Board, and all participants provided written informed consent. The sample size was set a priori to match the previous study's sample ($N = 40$). This sample is sufficient to detect the expected strong effects of task manipulations (e.g., trash-counting vs. free-viewing) on eye tracking and memory measures. Also, prior work on the effects of emotional image content on scene categorization and emotional responses has worked with similar and even smaller samples (e.g., [50, 51]), although we note that this work used far stronger manipulations (i.e., emotionally far more evocative content) compared to the current study. Participants whose glasses did not fit under the VR HMD and who had insufficient vision levels were immediately replaced, resulting in a final sample of 40 participants. Of these, 20 were randomly assigned to the trash-counting condition and 20 were assigned to the free-viewing condition (between-subjects).

2.2. Stimuli: Highway Billboards. We created visual billboards featuring various billboard-typical contents (see Figure 1). Specifically, out of the 20 billboards that every participant passed by while driving, 14 focused on health and risk topics, such as road safety, substance use, vaccination, and so forth; six of the 20 billboards focused on commercial topics, such as restaurants, coffee houses, hotels, or similar services. The billboards were designed using http://canva.com/ and the Midjourney AI image generation tool to resemble typical billboard/outdoor advertising designs (i.e., text + images; see Figure 1 for an example and the online repository at https://github.com/nomcomm/vr_billboard_e). For every billboard, we created two versions that varied in terms of emotional image saliency. Specifically, one version featured images with lower emotional saliency, the other higher. In doing so, the textual component of each message was kept exactly the same. To boost the emotional salience of the images, the following elements were added, informed by recent work on emotion elicitation, most notably work on emotional images [51–53]: people, people with emotional expressions (e.g., startled due to an imminent accident), and people in emotional situations (e.g., a sad person after losing a loved one and a person with a painfully red back due to sunburn). We confirmed that this manipulation of the images' emotional salience was highly successful by having all participants perform a 2-alternative forced choice (2AFC) test after the study. The test required participants to identify the billboard with higher emotionality. As shown in Table 1, the overall correct identification rate was very high,

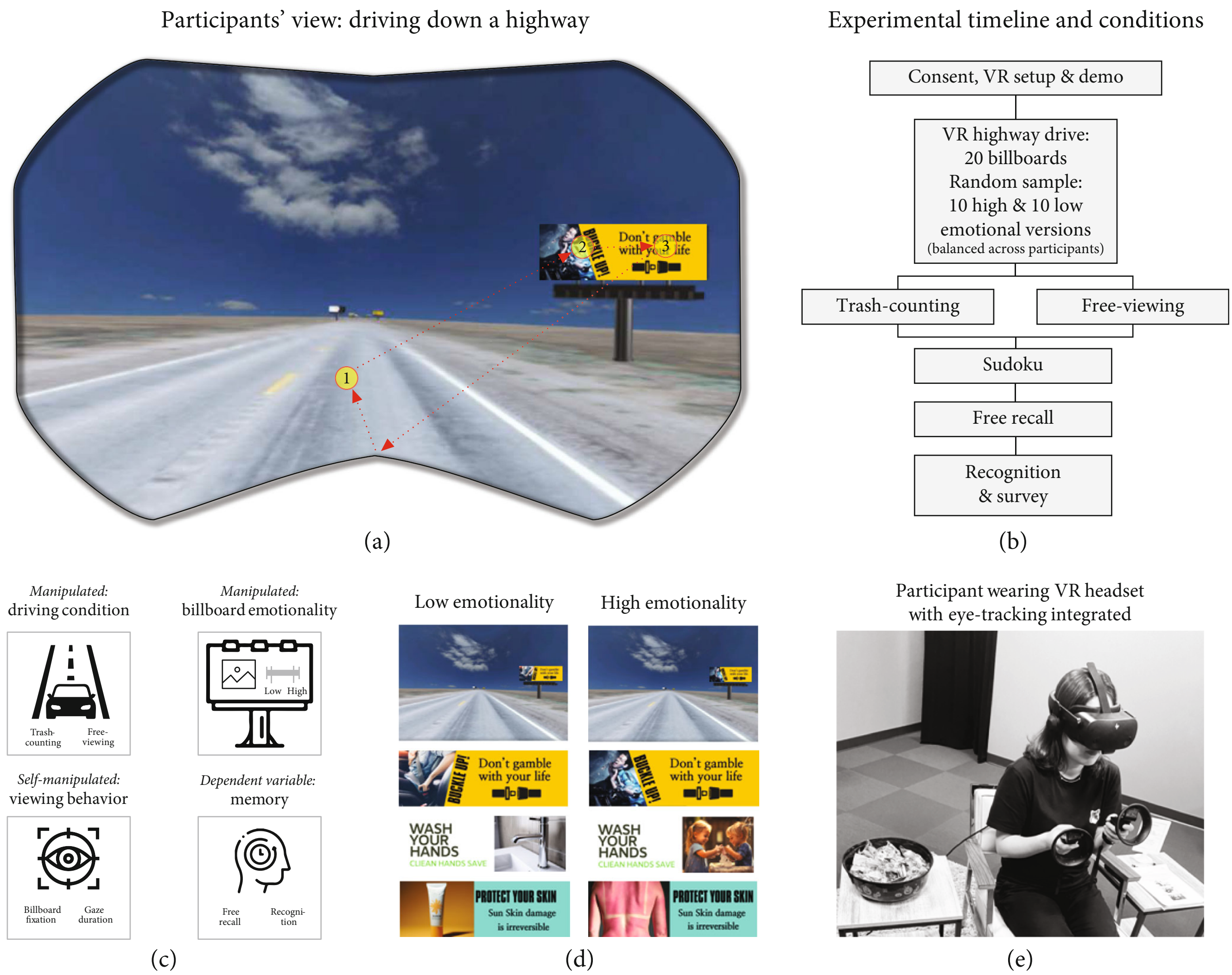

Figure 1: Study overview: experimental setup and manipulated variables. (a) Participant's view of the photorealistic highway environment with billboards. Superimposed (not visible to participants) is the eye-tracking scan path, which is used to determine whether a billboard was looked at. (b) Sequential diagram of study events and conditions. (c) Independent and dependent variables. (d) Illustration of low and high emotional billboard versions. (e) Lab setup. A participant wearing an HMD is engaged in driving along the virtual highway.

averaging 90.5%. This confirms that the manipulation of emotional image salience was correctly perceived by participants. Of note, we manipulated emotional image salience here by creating two examples (low and high) along the continuum of emotional image salience. However, the chosen examples were deliberately kept within a moderate range; that is, we did not show explicit or extreme motivational content; likewise, we did not attempt to manipulate discrete or basic emotions [52], which is difficult with images anyway, and we also manipulated only image content, keeping the textual message constant.

2.3. VR Environment and VR Device. The virtual environment that participants entered was a photorealistic version of Highway 50 in Nevada. This 3D model was provided by the Nevada DOT on http://sketchfab.com/ and was equipped with additional details (e.g., a sunny and blue-sky dome with clouds and empty soda cans on the highway for the trash-counting task).

The created billboard images were placed along this virtual highway on typical billboard stands. The order of the 20 billboard topics was fully randomized across viewers. Moreover, an elaborate assignment schema was devised so that pairs of participants received exact opposite emotional salience versions (i.e., low vs. high) of the billboards, which were otherwise presented in the exact same order (e.g., sub001: #1 burger_low_emo, #2 hotel_low_emo, #3 drugs_high_emo and sub002: #1 burger_high_emo, #2 hotel_high_emo, #3 drugs_low_emo). This mode of presentation ensures that all billboard versions are shown equally often and under conditions that are maximally comparable.

The VR headset was HP Reverb G2 Omnicept, which includes an embedded high-precision eye-tracker. Participants used the VR controller to drive forward on the virtual highway. There was no need for the participants to steer as the Highway 50 model is perfectly straight.

2.4. Experimental Procedure and Conditions: Virtual Drive Down the Highway. After consent and VR preparation procedures were completed, participants first entered a demo

TABLE 1: Number and percentage of participants who correctly identified emotional salience in the 2AFC test.

No.	Billboard message topic	*n* (%)
1	Binge drinking	38 (95)
2	Buckling up	37 (92.5)
3	Diabetes	28 (70)
4	HIV	37 (92.5)
5	Texting and driving	32 (80)
6	Drugged driving	36 (90)
7	Smoking	38 (95)
8	Sun protection	39 (97.5)
9	Handwashing	37 (92.5)
10	Vaccination	35 (87.5)
11	Vaping	38 (95)
12	Marijuana	32 (80)
13	Technology overuse	38 (95)
14	Healthy diet	38 (95)
15	Brunch	38 (95)
16	Burger	37 (92.5)
17	Coffee	38 (95)
18	Education donation	39 (97.5)
19	Furniture	35 (87.5)
20	Hotel	34 (85)
	Total	40 (100)

environment to familiarize themselves with VR and how to use the controller to drive forward. Next, for the main session, they were instructed according to their assigned condition. Half of the participants ($n = 20$) were instructed to count the number of trash items on the highway (trash-counting condition; distraction condition); the other half were instructed to freely drive down until they reached the end (free-viewing condition, $n = 20$). After the driving experience, which took about 5–7 min, participants were asked to work on Sudoku puzzles (2 min, serving to clear their working memory from the last billboards just passed), followed by a structured interview.

During this interview, the experimenter asked participants in the trash-counting condition how many trash items they counted and about their general VR driving experiences. The interviewer then asked participants to list all billboards they could recall passing by (i.e., free recall). Finally, participants completed an online survey. This survey first asked them about VR experiences (spatial presence, occurrence of symptoms, and technology usability), followed by a visual recognition test of billboards. Specifically, for this recognition test, participants were shown all 20 billboards with both low- and high-emotional versions and four distractors. Then they were asked for each of the two versions of the billboard images whether they recognized seeing one of the versions while driving along the highway. If they answered yes to indicate they recognized seeing one of the two versions of the billboards, they were further asked to indicate their level of confidence. For this, the two billboard versions were shown at opposite ends of a bipolar matrix, and participants indicated how confident they were having seen one or the other version (the middle point indicating uncertainty). Last, participants viewed all billboard versions and selected the more emotional one for each alternative version (forced choice, manipulation test). Finally, participants were debriefed, and data were archived.

2.5. Data Processing, Analysis, and Main Measures. This experimental setup yields the following objective data: First, from the VR system's output, we receive information about where participants were looking and particularly whether they fixated on a given billboard while passing it (a dynamic/VR-based region of interest). In addition to assessing whether a billboard was fixated, we also measured for how long it was looked at in total (gaze duration) and how often it was looked at (in case of multiple fixations). By merging these viewing behaviors with the type of billboard that was displayed in a given position for a given participant (e.g., the billboard content as well as the low/high-emotional version), we can derive a list of which billboards and at which locations were viewed. Since billboard images were randomly allocated to specific billboard sign positions, a Python script was developed to reorganize the individual images based on a participant's eye-tracking data (e.g., time 15 s, billboard_1, and drunk_driving_high_emo.jpg). This facilitates subsequent data aggregation across participants and messages.

Second, from the interview and recognition survey, we can derive two metrics of message memory: free recall and recognition. These metrics are again captured at the individual level, that is, whether participant X recalled banner Y, recognized banner Y, and which version of the billboard they saw. Thus, the central analytic dataset combines the following sources of information: (1) which billboard (e.g., smoking, texting, and driving) and in which version (low vs. high emotionality) was displayed at which position (1,2,…,20) along the highway; (2) whether a given participant looked at (i.e., fixated) this billboard, how often this happened in the case of multiple refixations, and how long in total (gaze duration); (3) lastly, from the interview and the survey, we obtain measures of free recall and recognition, respectively (i.e., recalled/not recalled and recognized/not recognized). Overall, with 40 participants and 20 billboards, we thus obtained a data frame with 800 rows. Twenty participants were in the trash-counting and 20 participants in the free-viewing condition, and each of the participants saw 10 low and 10 high emotional versions of the billboards.

In the analysis, we first conducted a stream of two separate repeated-measures ANOVA analyses to demonstrate the effects of our manipulations (driving condition: trash-counting vs. free-viewing and billboard emotional salience: low vs. high) on the viewing behavior towards the billboards (fixations and gaze duration) and on memory for the billboards (free recall and recognition), respectively. Then, we brought together the information about fixations (whether a billboard was actively looked at) and memory in a joint model together with the experimentally manipulated variables. Said differently, we can think of the viewing behavior metrics as another variable (representing the nexus where exposure turns into reception). However, contrary to typical laboratory studies where exposure is forced onto participants, our study let participants look freely (either completely freely or taxing their attention with a competing trash-counting task, which did, however, still leave them some choice). Thus, variable viewing behavior varies from subject to subject based on their idiosyncratic viewing behavior. To statistically analyze these data, we specified a logistic (generalized) mixed effects model in which recall (or recognition, respectively) formed the dependent variables and driving condition, billboard emotionality, and viewing behavior were the predictors of interest. Further, to account for potential differences between billboard messages and individual subjects, we specified those two variables as random effects and controlled for their varying intercepts [54–56].

3. Results

We used a VR environment with an integrated eye-tracker to rigorously quantify message exposure and link it to message memory. Specifically, participants drove down a virtual highway along which billboards were placed, allowing us to manipulate billboard messages (less vs. more emotional variants) and tasks (trash-counting vs. free-viewing). Then, we captured whether they fixated on the billboards in passing (fixation vs. no fixation) as a ground-truth measurement of actual exposure. Finally, we measured message recall and message recognition.

3.1. Participants' Subjective Experiences in VR. First, to demonstrate how participants experienced the drive, we examined their responses from verbal interviews conducted right after they came out of VR. Participants generally commented that they found the virtual highway drive to be realistic and captivating. This was further supported by the postexperimental survey data, which showed that participants reported a high level of spatial presence in the VR environment ($\text{mean}_{\text{spatial presence}} = 3.61$, $\text{SD} = 0.71$ on a scale of 1–5, with all items scoring above the midpoint; [57]). Additionally, participants reported minimal symptoms such as dizziness, fatigue, or eyestrain ($\text{mean}_{\text{VR symptoms}} = 1.42$, $\text{SD} = 0.36$ on a scale of 1–4, with all items below the midpoint; [58]).

3.2. Effects of Experimental Manipulations on Viewing Behavior and Memory. Next, we examined how the experimental manipulations (*billboard emotional salience*: low vs. high and *driving condition*: trash-counting vs. free-viewing) impact participants' *viewing behavior* (fixations on billboards and gaze duration) and *memory* (free recall and recognition), assessed separately. Results for the effects of experimental manipulations on viewing behavior are illustrated in Figure 2; the results for the effects of experimental manipulations on memory are illustrated in Figure 3, and data are provided in Tables 2 and 3.

3.2.1. Effects on Viewing Behavior. As expected, participants in the "free-viewing" *driving condition* were significantly more likely to fixate on a billboard (ca. 90%) than participants in the "trash-counting" driving condition (ca. 55%; $F_{\text{Driving Condition}}(1, 38) = 14.983$, $p < 0.001$, $h^2 = 0.271$; see Figure 2a). There was no main effect of *billboard emotional salience* ($F_{\text{Billboard Emotional Salience}}(1, 38) = 0.056$, $p = 0.814$), and the interaction effect between *billboard emotional salience* (low vs. high) and *driving condition* (trash-counting vs. free-viewing) on fixation probability was not significant ($F_{\text{Driving Condition X Billboard Emotional Salience}}(1, 38) = 0.056$, $p = 0.814$). Thus, the effect of the driving conditions on fixation probability was not significant regardless of the billboard's emotionality.

A very similar pattern of results was obtained for the gaze duration as the dependent variable. As can be seen in Figure 2b, participants in the "free-viewing" *driving condition* were not only more likely to look at a billboard, but they also looked longer at it if they did ($F_{\text{Driving Condition}}(1, 38) = 21.515$, $p < 0.001$, $h^2 = 0.348$). For the gaze duration measure, the main effect of *billboard emotional salience* was marginally significant ($F_{\text{Emotional Salience}}(1, 38) = 4.050$, $p = 0.051$, $h^2 = 0.004$), suggesting that the highly emotional billboards were looked at for slightly longer. Again, there was no significant interaction effect ($F_{\text{Driving Condition X Billboard Emotional Salience}}(1, 38) = 1.485$, $p = 0.230$). Thus, our results supported H3 and partially supported H1.

3.2.2. Effects on Memory Performance. Next, we examined whether participants' memory (assessed via free recall and recognition, respectively) differed as a function of *driving condition* with their respective low (free-viewing) or high (trash-counting) attentional demands and the *billboard emotional salience* (less vs. more emotional content) factor (see Figure 3). Participants in the "free-viewing" *driving condition* recalled significantly more billboards than participants who drove by the billboards while counting trash ($F_{\text{Driving Condition}}(1, 38) = 11.756$, $p = 0.001$, $h^2 = 0.134$). The interaction effect between the recall rate of emotionally salient messages (more vs. less) and the driving conditions (trash-counting vs. free-viewing) was significant ($F_{\text{Driving Condition X Billboard Emotional Salience}}(1, 38) = 4.208$, $p = 0.047$, $h^2 = 0.043$). Participants in the free-viewing driving condition recalled more emotionally salient billboards ($\text{mean}_{\text{recall rate: free-viewing, more emotionally salient}} = 0.33$, $\text{SD} = 0.17$) than less emotionally salient billboards ($\text{mean}_{\text{recall rate: free-viewing, less emotionally salient}} = 0.24$, $\text{SD} = 0.12$), whereas participants in the trash-counting driving condition recalled slightly lower emotional than more emotionally salient billboards ($\text{mean}_{\text{recall rate: trash-counting, more emotionally salient}} = 0.15$, $\text{SD} = 0.11$; $\text{mean}_{\text{recall rate: trash-counting, less emotionally salient}} = 0.19$, $\text{SD} = 0.17$). The main effect of *billboard emotional salience* was not significant ($F_{\text{Billboard Emotional Salience}}(1, 38) = 0.623$, $p = 0.435$).

Performing the same analysis for the recognition memory revealed a highly significant main effect of *driving condition* ($F_{\text{Driving Condition}}(1, 38) = 14.515$, $p < 0.001$, $h^2 = 0.229$). Participants in the free-viewing condition recognized significantly more billboards than participants who drove by the

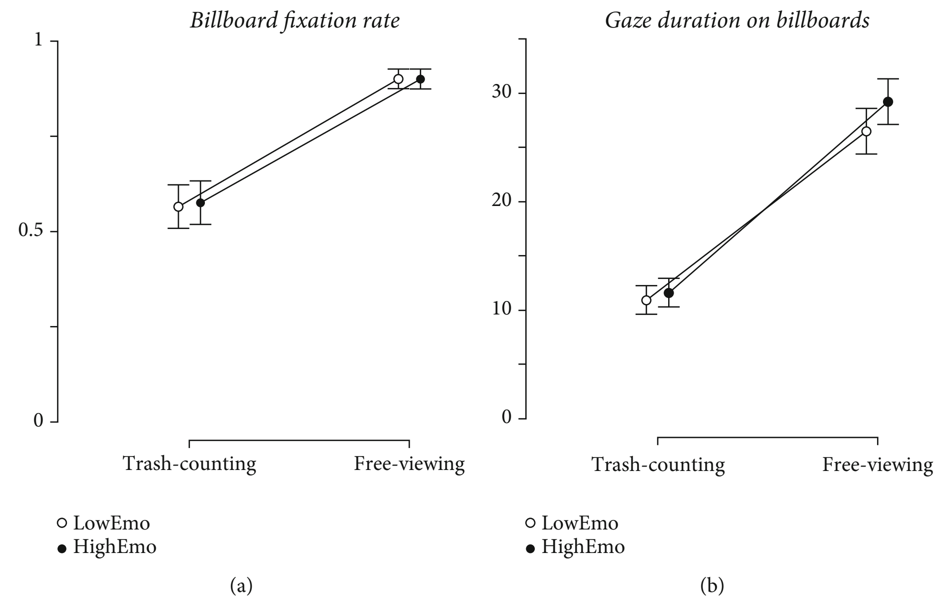

Figure 2: Effects of billboard emotional salience and driving condition on viewing behavior. (a) Probability of fixating a billboard as a function of driving task (trash-counting vs. free-viewing) and billboard emotional salience (less vs. more salient). As can be seen, in the free-viewing condition, participants are far more likely to fixate on a billboard (on average, 18/19 out of 20 billboards are fixated), whereas in the trash-counting condition, only about half of the billboards are fixated (i.e., looked at least once). (b) The same analysis, but for the gaze duration measure, that is, the sum of the total fixation duration across all billboards that were at least once fixated.

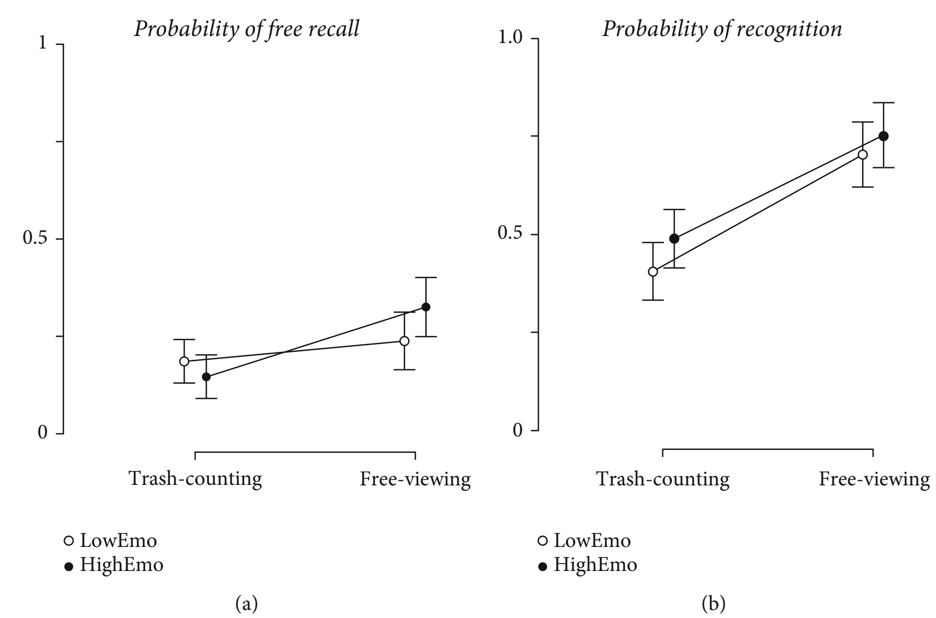

Figure 3: Effects of billboard emotionality and driving condition on memory. (a) Probability of recall (i.e., freely mentioning a billboard after the virtual highway drive ended so that it could be identified). (b) Probability of recognition, as measured in the postexperimental survey (note about guessing correction/signal detection analysis).

TABLE 2: Means (SDs) and statistical results for effects of experimental manipulations (billboard emotional salience and driving condition) on viewing behavior (unique fixations and gaze duration).

Effects on viewing behavior		Unique fixations mean (SD)		Gaze duration mean (SD)	
		Billboard emotional salience			
		High	Low	High	Low
Driving condition	Free-viewing	0.9 (0.2)	0.9 (0.18)	29.20 (12.72)	26.49 (12.97)
	Trash-counting	0.58 (0.35)	0.57 (0.34)	11.60 (9.93)	10.93 (10.51)
Statistics		$F_{\text{Driving Condition}} = 14.983$, $p < 0.001$		$F_{\text{Driving Condition}} = 21.515$, $p < 0.001$	
		$F_{\text{Emotional Salience}} = 0.056$, $p = 0.814$		$F_{\text{Emotional Salience}} = 4.050$, $p = 0.051$	
		$F_{\text{Interaction}} = 0.056$, $p = 0.814$		$F_{\text{Interaction}} = 1.485$, $p = 0.230$	

TABLE 3: Means (SDs) and statistical results for effects of experimental manipulations (driving condition and billboard emotional salience) on memory (free recall and recognition).

Effects on message memory		Free recall rate mean (SD)		Recognition rate mean (SD)	
		Billboard emotional salience			
		High	Low	High	Low
Driving condition	Free-viewing	0.33 (0.17)	0.24 (0.12)	0.76 (0.23)	0.71 (0.19)
	Trash-counting	0.15 (0.11)	0.19 (0.17)	0.49 (0.32)	0.41 (0.30)
Statistics		$F_{\text{Driving Condition}} = 11.756$, $p = 0.001$		$F_{\text{Driving Condition}} = 14.515$, $p < 0.001$	
		$F_{\text{Emotional Salience}} = 0.623$, $p = 0.435$		$F_{\text{Emotional Salience}} = 3.183$, $p = 0.082$	
		$F_{\text{Interaction}} = 4.208$, $p = 0.047$		$F_{\text{Interaction}} = 0.214$, $p = 0.646$	

billboards while counting trash. The main effect of *billboard emotional salience* was not significant, although a trend was seen ($F_{\text{Billboard Emotional Salience}}(1, 38) = 3.183$, $p = 0.082$) for more emotional billboards to be recognized more often. For recognition memory, there was no interaction effect between *driving condition* and *billboard emotional salience* ($F_{\text{Driving Condition X Billboard Emotional Salience}}(1, 38) = 0.214, p = 0.646$).

3.3. Examining Message Memory as a Function of Viewing Behavior (Exposure), Driving Condition (Attentional Resources), and Billboards' Emotional Salience (Attention-Attracting Image Characteristics)

3.3.1. Strong Effect of Viewing Behavior on Memory. Having examined how the experimental factors *driving condition* and *billboard emotional salience* impact participants' *viewing behavior* and *memory*, we next moved on to consider how *driving condition*, *billboard emotionality*, and *viewing behavior* jointly impact *memory* (see Figure 4). First, we confirmed that participants' individual *viewing behavior* strongly impacts *memory*. To this end, we specified a generalized linear mixed model (GLMM) to test the effects of all experimentally manipulated factors (*driving condition* and *billboard emotional saliency*) as well as the self-manipulated factor *viewing behavior* (fixation, whether a participant looked at a given billboard or not) on memory outcomes. For message recall as the outcome, a significant and dominant effect of *viewing behavior* (*fixation* vs. *no fixation on a billboard message*) confirmed that whether a billboard was fixated (looked at) or not strongly affects the probability of recall ($\chi^2_{\text{Viewing Behavior}} = 43.430$, $p < 0.001$). Likewise, conducting the same analysis for message recognition as the outcome, a significant dominant effect of fixation on recognition was observed ($\chi^2_{\text{Viewing Behavior}} = 14.413$, $p < 0.001$). Additionally, for recognition (but not for recall), the effect of *driving condition* (free-viewing vs. trash-counting) was also significant ($\chi^2_{\text{Driving Condition}}(\text{df} = 1) = 10.953$, $p < 0.001$). The results are illustrated in Figure 4, and they are consistent with the proposed causal influence of *actual exposure* as the dominant and causal link in the chain from message content to message effects.

3.3.2. Memory for Messages That Were Looked at (Exposed/Actually Seen) as a Function of Driving Condition and Billboard Emotional Salience. Having demonstrated that the self-determined *viewing behavior* strongly affects memory (both measured via recall or recognition), we zoomed in on only those billboards that were looked at, that is, the ones for which we can objectively claim that participants were exposed to them (see Figure 5). A GLMM for the recall data from all looked-at billboards revealed a statistically significant interaction effect between *driving condition* (trash-counting vs. free-viewing) and the *billboard emotional salience* (low vs. high) ($\chi^2_{\text{Driving Condition X Emotional Salience}} = 4.522$, $p = 0.033$; $\text{mean}_{\text{Recall: Trash Counting - More Emotionally Salient}} = 0.222$, 95% CI [0.142, 0.329]; $\text{mean}_{\text{Recall: FreeViewing - More Emotionally Salient}} = 0.341$, 95% CI [0.25, 0.446]; $\text{mean}_{\text{Recall: TrashCounting - Less Emotionally Salient}} = 0.271$, 95% CI [0.18, 0.386]; $\text{mean}_{\text{Recall: FreeViewing - Less Emotionally Salient}} = 0.225$, 95% CI [0.154, 0.317]). Specifically, for participants

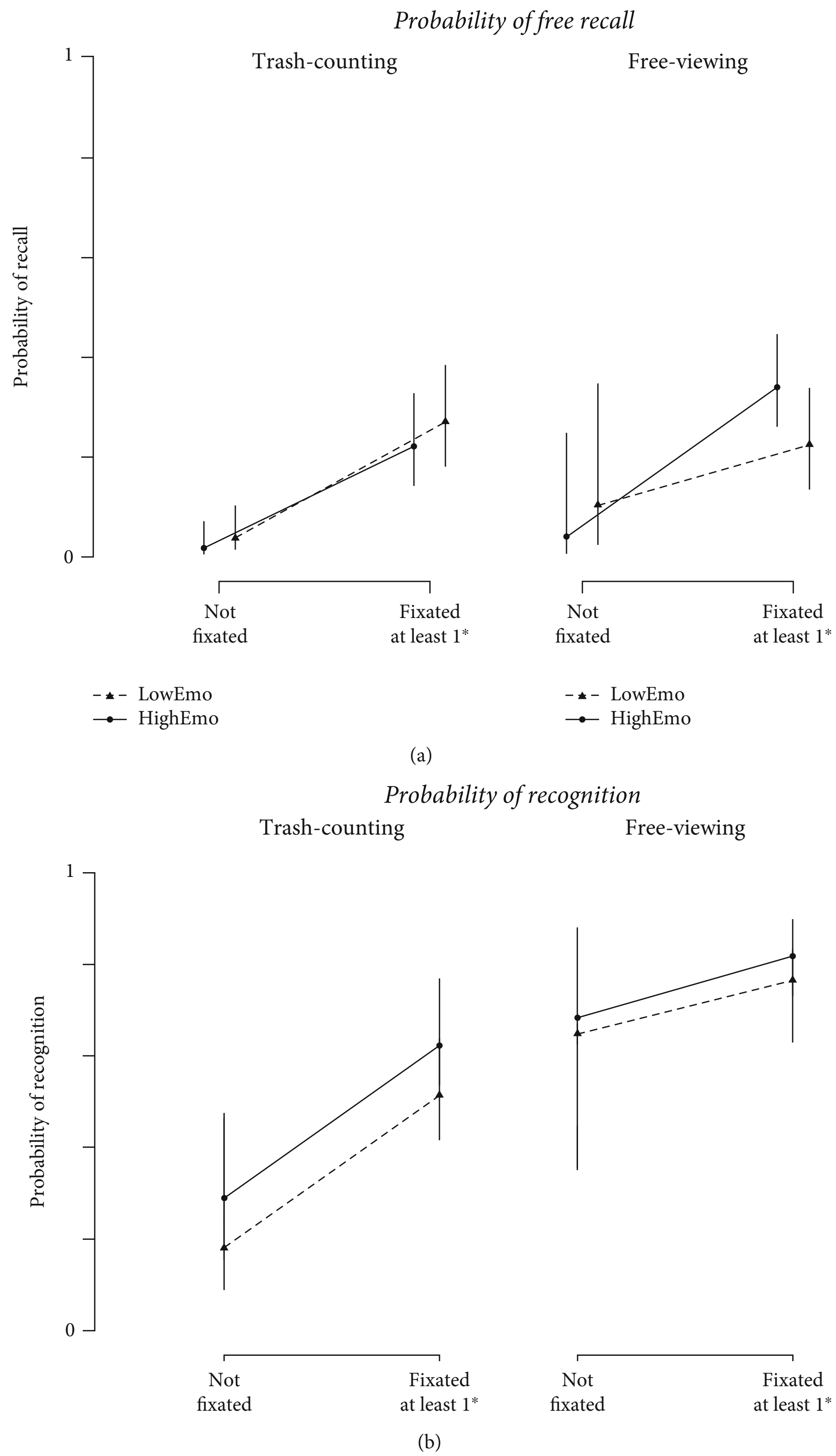

Figure 4: Joint model of experimentally manipulated variables (driving condition and billboard emotional salience) and subject-determined behavioral manipulation (viewing behavior, i.e., whether a billboard was fixated or not) on memory outcomes. (a) Results for free recall (left: trash-counting; right: free-viewing). (b) Results for recognition memory.

who were instructed to count trash, the recall rate did not differ much between the high- and low-emotionality billboards, but in the free-viewing driving condition (where participants resources were not taxed by counting trash), the recall rate was higher for more emotionally salient billboards compared to the less salient exemplars.

Conducting the same analyses for the recognition memory using a GLMM, we observed a significant main effect of

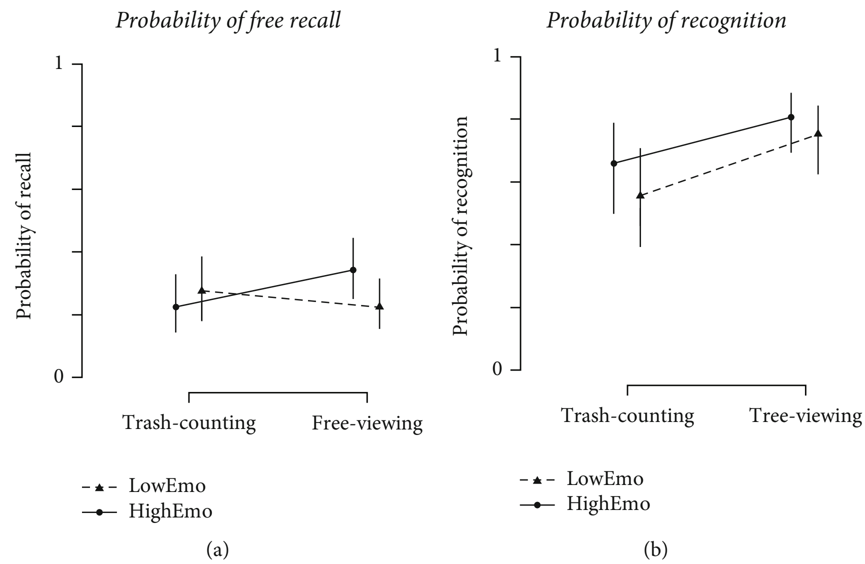

Figure 5: Zooming in on effects of billboard emotional salience and driving condition on memory for fixated billboards only (i.e., certain exposure). (a) For the recall memory measure, a significant interaction is observed. Particularly during the free-viewing condition, highly emotional messages are remembered best. (b) For the recognition memory measure, two main effects emerge. Free-viewing leads to better memory and more emotional messages are more often recognized.

driving condition, with better memory performance in the free-viewing condition ($\chi^2_{\text{Driving Condition}} = 5.361$, $p = 0.021$; $\text{mean}_{\text{Recognition: TrashCounting - More Emotionally Salient}} = 0.663$, 95% CI [0.501, 0.795]; $\text{mean}_{\text{Recognition: FreeViewing - More Emotionally Salient}} = 0.812$, 95% CI [0.696, 0.891]; $\text{mean}_{\text{Recognition: TrashCounting - Less Emotionally Salient}} = 0.558$, 95% CI [0.393, 0.711]; $\text{mean}_{\text{Recognition: FreeViewing - Less Emotionally Salient}} = 0.756$, 95% CI [0.625, 0.852]). Additionally, there was a marginally significant main effect of *emotional salience* on memory recognition, with more emotional messages tending to be better recognized ($\chi^2_{\text{Billboard Emotional Salience}} = 3.645$, $p = 0.056$).

3.4. Additional Analysis of Dose–Response Relationships. Does more intense viewing lead to better memory? The analyses presented in the previous section are based on a dichotomous conceptualization of exposure, defined as whether participants did or did not look at a given billboard at all. However, a more nuanced view can be provided by a gradual analysis that focuses on dose–response relationships. To this end, we went back to the original data and reanalyzed—for every participant and every billboard—how often (fixation count) they looked at a billboard. Specifically, we split every participant's fixation data to form three bins: billboards that were never looked at, billboards that were looked at some (but less than that participant's median number of fixations), or billboards that were looked at a lot (more than the median number of fixations). For each of those three classes of billboards, we analyzed the subsequent memory performance. The results are shown in Figure 6 and revealed a very clear picture: For both recall and recognition memory, significant main effects of viewing behavior intensity and driving condition were qualified by a significant interaction. Although even in the trash-counting driving condition more fixated billboards tended to be better memorized, these effects were more strongly pronounced in the free-viewing driving condition (recall: $F_{\text{Viewing Behavior Intensity}}(2, 76) = 65.265$, $p < 0.001$, $h^2 = 0.47$; $F_{\text{Driving Condition}}(1, 38) = 11.756$, $p = 0.001$, $h^2 = 0.051$; $F_{\text{Viewing Behavior Intensity}*\text{Driving Condition}}(2, 76) = 5.499$, $p = 0.006$, $h^2 = 0.04$; recognition: $F_{\text{Viewing Behavior Intensity}}(2, 76) = 30.097$, $p < 0.001$, $h^2 = 0.327$; $F_{\text{Driving Condition}}(1, 38) = 14.515$, $p < 0.001$, $h^2 = 0.057$; $F_{\text{Viewing Behavior Intensity}*\text{Driving Condition}}(2, 76) = 4.975$, $p = 0.009$, $h^2 = 0.054$). These data confirm dose–response relationships, which are an important topic in health communication at the aggregate level [59] but are demonstrated to matter here even at the level of microlevel reception data. Put simply, the more a billboard is inspected, the better the memory.

4. Discussion

This study examined the causal link between exposure, reception, and retention within a controlled experimental setting and specifically the influence of attention-manipulating factors—message emotionality and driver distraction (i.e., trash-counting [search task] vs. free-viewing [free inspection])—on exposure and retention. Our results confirm that exposure determines all subsequent effects that distraction impacts the likelihood of exposure, and that both, the manipulation of distraction and emotional content, affect retention. Below we discuss these results and their theoretical significance, including how the current approach advances our mission to reveal the mechanisms from messages in the environment to their effects on audiences.

First, we observed strong effects among driving conditions, fixations, and memory. The participants in the free-viewing condition (i.e., nondivided attention) were about 1.5 times more likely to fixate on a billboard and look at it for a longer period (gaze duration) than those in trash-

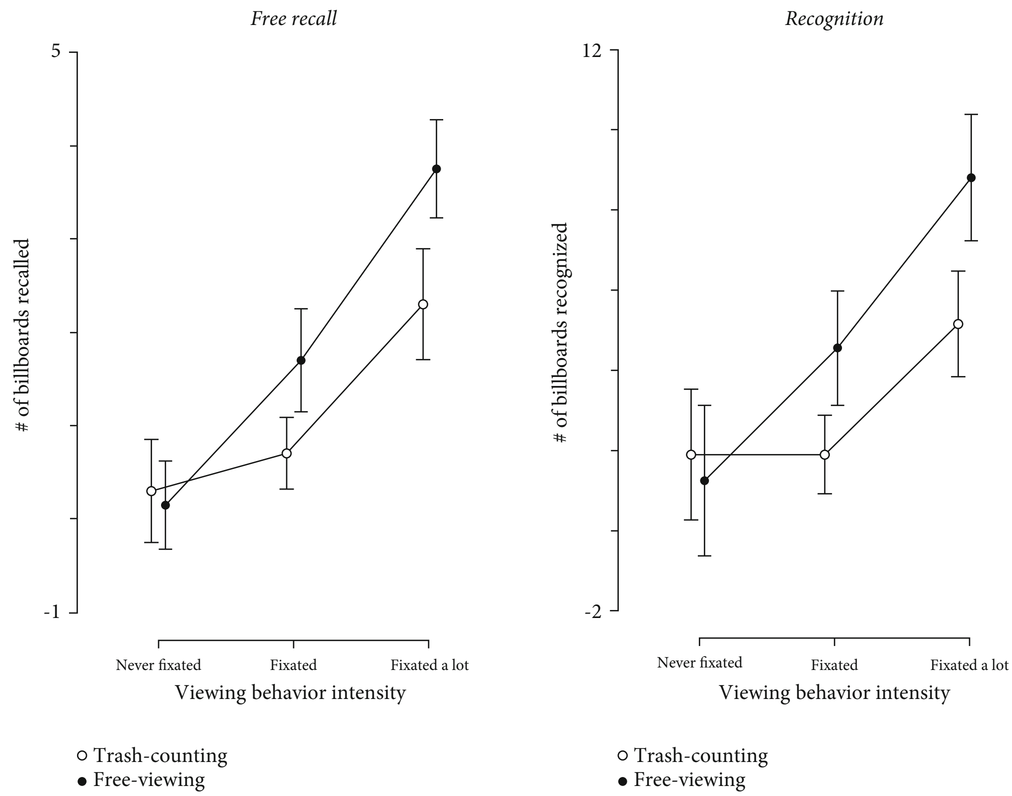

Figure 6: Results from additional analyses of dose–response relationships.

counting condition (i.e., divided attention, see Figure 2). As we predicted, the participants in the free-viewing condition recalled and recognized more billboards (see Figure 3). These results align with existing studies about the link between attention and memory (e.g., [16, 35, 60]). Thus, our results show that actual exposure (i.e., "fixating on the billboard") explains variance in message memory [61], and they underscore the importance of studying the exposure–reception–retention nexus in an integrated manner [49].

Next, we turn to the influence of message emotionality on gaze behavior (fixation likelihood and gaze duration) and memory. As can be seen in Figure 4—and contrary to our predictions—the emotional salience of the billboards did not strongly affect whether or not people fixated on the message. However, more emotionally salient messages were looked at for a longer period compared to the less salient messages (marginal statistical significance), supporting H1b. Interestingly though, when zooming in only on the messages that were fixated (see Figure 5), we found that the effect of emotional salience on memory varied by the driving condition (i.e., available attention) and the type of memory. Participants in the free-viewing condition recalled slightly more emotionally salient messages compared to the less salient messages.

Taken together, our two manipulations impacted *whether* and *how* participants looked at and remembered the messages. The distraction manipulation had very strong main effects on viewing behavior (fixation rate and duration) and memory (recall and recognition). The effects of billboard emotionality were not as strong, and the most conspicuous effect was for fixated billboards (for which we can be sure that exposure happened); the recognition memory revealed a main effect of emotional salience (more emotional billboards being recognized better); this effect was similarly expressed across both driving condition groups, demonstrating consistency. However, when memory was assessed via free recall, which is more difficult as it requires the active retrieval of a memory trace, the pattern of results was different. Under free-viewing conditions, that is, when less attention was consumed by the competing task of trash-counting, we observe higher recall of more emotional messages. But in the trash-counting condition, which required deploying attention on the road, the more emotional billboard versions were not more successful in attracting attention or boosting memory. One potential reason behind the observed differences in driving conditions, trash-counting vs. free-viewing, may be discussed in relation to the distinct demands each imposes on individuals. The introduction of the trash-counting task is not merely a matter of adding visual distractions (in fact, the trash items—a variety of soda cans—were always present, but only the participants in the trash-counting condition had to look out for them). Rather, the task-counting instruction fundamentally alters the participants' mindset by shifting from a free inspection approach to a more targeted search task [62], and it also imposes additional demands on working memory to keep track of the number of encountered trash items. This difference in task demands clearly changes how participants scan their environment visually, and it also likely constrains available working resources (by having to count and keep track of the items; e.g., [37]). This, in turn, may leave less capacity to first detect and then more deeply process the billboards and particularly their varying emotionality (less vs. more salient). Indeed, previous work in experimental psychology and cognitive and affective neuroscience has tried to study how nonemotional and more emotional aspects interfere with working memory tasks (e.g., [63, 64]). Obviously, our specific task manipulation (trash-counting) is only one of many possibilities (others being, e.g., competing tasks like extremely taxing n-back tasks, or competition from other highly emotional items, or even attention to emotion, or other more sensory or more cognitively demanding alterations). Thus, while the available evidence is compatible with the view that load during the trash-counting task may have suppressed the salience of billboard emotionality, more work is needed to specify the boundary conditions of how driving tasks and billboard emotionality may interact. Overall, by using VR and an integrated eye-tracker in this billboard paradigm, we were able to manipulate participants' attention, unobtrusively capturing their viewing behavior in space and time and linking this information to memory outcomes.

4.1. Implication 1: Measuring Actual Exposure. The theoretical significance of our results lies in the clear, simple, and objective insights they offer into the exposure–reception–retention nexus. Specifically, the way in which exposure was measured in prior research leaves a lot to be desired. Measuring exposure at an aggregate level is different from measuring it in a given individual [2, 65]; measuring exposure via self-report is potentially subject to recall bias [66]; and last, laboratory studies can examine forced exposure but not the kind of incidental exposure that matters in real life [67]. Thus, it is safe to say that the theoretical phenomenon in question—actual exposure in ecological settings—has barely been measured. This poses a significant theoretical challenge insofar as exposure has been termed the foundation of all message effects (e.g., [38]). In this sense, the current study not only makes a methodological contribution but also provides a great example of the old adage that there is nothing so theoretical as a good method [68].

4.2. Implication 2: Unpacking the Mechanisms of Emotional Message Processing. Beyond rigorously quantifying actual exposure, the current study manipulated the messages' emotional content. The underlying reasoning was that there is a logical chain from message content (e.g., a billboard displaying a picture of a road accident with a textual warning to avoid texting and driving) to exposure and reception (the driver passing the billboard and looking at it), and on to retention (the driver recalling or recognizing this message; [49]). The goal of communication message design is to manipulate specific message characteristics to affect this chain—from increasing the likelihood of exposure to facilitating sustained attentional engagement to boosting memory encoding (e.g., [69, 70]). For instance, by increasing the physical image salience (e.g., via contrast or flashing lights around the billboard), one can attract a gaze, and the underlying perceptual and cognitive mechanisms are fairly well understood [71]. Beyond image salience, however, most researchers are more interested in higher level message characteristics, like the effects of emotional appeals, framing, or narratives [69].

Here, we focused on the emotional visual content of the messages, creating two well-matched versions of each billboard (one more, the other less emotional; [72]). This also aligns with decades of communication research, particularly the seminal work on the effects of fear appeals [73, 74], although we note that we did not manipulate fear specifically (most of our high-emotion billboards depicted high-arousing negative consequences, like accidents or sunburn, which would be considered a threat appeal). The assumption was that by making the visual billboard content more emotional, they would be more likely to be looked at, more intensely inspected, and ultimately more likely to be stored [75]. Indeed, neuroscientific research on affective vision strongly supports that emotional images are prioritized and amplified across processing stages—from early vision to memory formation [22, 76].

However, the current results only partially supported this. Although overall, more emotional images were somewhat better remembered, the effects of this manipulation were much weaker than the effects of the driving condition (distraction). Likewise, emotional images were not vastly more likely to be fixated, but once they were fixated, people indeed tended to look at them more often. In retrospect, these results make sense given that our manipulation of emotional salience was fairly weak. Specifically, research on emotional images tends to be done with very strong imagery, like pictures of strong mutilations and erotica [22], whereas our emotional content manipulations spanned across a more moderate range of emotional salience (i.e., only depicting a startled driver but not a blood-splattered car wreck as in a full-blown fear/threat appeal). With this in mind, the current results seem reasonable and demonstrate that despite a weak manipulation of emotional image content, some processing advantage is detectable (and our postexperimental forced choice task confirms that participants were able to detect the more emotional billboards). Although the effect size of this manipulation is moderate and barely significant with a sample of 40 participants, these effects could still matter practically if we consider that typical roadside billboards are passed by thousands of passengers every day [77].

4.3. Implication 3: Opportunities for Examining Message Effects in Real and Virtual Environments. Going forward, future work should expand the range of message characteristics and study the effects of those manipulations—even beyond the retention of messages in memory. As discussed above, it would seem possible to increase the strength of our emotion manipulation, and doing so should lead to stronger effects. Here, we focused primarily on the emotional salience of the image content and its effects on the initial visual-attentional processing. However, given that much emotion research also examines discrete emotions beyond the arousal/intensity axis, one could specifically zoom in on, for example, guilt appeals, humor, or other specific emotions [72], that is, processes that occur after initial evaluations of the emotional content based on later appraisals.

It is clear that the current VR billboard paradigm offers a lot of flexibility for additional manipulations. For instance, here, we only manipulated the billboard's visual content but kept the billboard's textual content perfectly controlled. Going forward, it is clearly possible to also manipulate text content, for instance, by adding framing manipulations, short narratives, testimonials, or other kinds of manipulations [69]. Also, because the VR-based paradigm is exquisitely suited to allow for any experimental manipulation—even ones that would not be possible in reality—we see a lot of opportunities for this paradigm to study the effects of manipulations of message characteristics and task demands. To name but a few examples, communication and also advertising researchers have long been concerned with the effects of various emotions, such as fear, anger, or guilt, on attention and retention (e.g., [72, 78]). Thus, while we chose here to first focus on variations in the degree of emotional salience, future work could definitely resolve the dynamics of attending to, consolidating, and then retrieving emotional messages. Likewise, focusing, for example, on product preferences or even choice beyond the recall of seen messages would seem like a promising next step.

We also note that much of eye-tracking–based message effects research is limited insofar as it uses stationary eye trackers [79–81]. Stationary eye-trackers offer valid insights into scanpaths on websites, but this limits the messaging contexts to mostly screen-based study contexts. However, if the goal is to understand how people look for and react to messages in more naturalistic information environments, a different approach is needed [44, 67, 82]. In the case of billboard advertising, for instance, people navigate through space, their eyes wander and constantly select information, and the relevant target objects (in this case billboards) change size as people approach and then pass them. The strength of the VR- and eye-tracking paradigm presented here is that it cannot only cope with these complexities but it also offers great flexibility in terms of potential messaging contexts that could be studied. Indeed, the same basic argument can be made for other kinds of outdoor advertising, like in inner cities and malls, but it could also be made, for example, for finding signs in hospitals and hallways (e.g., [48]). As long as relevant environment and message features can be isolated, we can now manipulate them and examine how VR-immersed users behave when experiencing these carefully crafted but realistic communication ecosystems [45].

The current paradigm also has broad applied implications, particularly regarding messaging and advertising in natural and future metaverse communication environments. In addition to the reliance on objective measures (overt attention captured via eye-tracking), a core strength of the VR-based approach taken here is its near-infinite flexibility regarding the types of contexts one could study. The current paradigm was situated in a highway and billboard advertising context, but it is easy to see how this can be transferred to, for example, an urban environment, a railway station, or any other outdoor advertising. But even in the highway-driving context alone, we see several practical applications, like providing legal evidence about the impact of roadside advertising, empirical billboard efficacy measurement, or simulations for billboard construction planning. Finally, and perhaps most importantly, we consider the emerging Metaverse and its implications for empirical communication research. Unlike traditional VR environments that serve as models of the real world, the Metaverse will function as an actual setting where people spend time and engage with messages. This shift means that the current approach can be directly applied to studying user interactions with messages in this digital space. Given the profound impact of digital user metrics—such as click-through rates and page impressions—on the internet and major platforms like Facebook, Twitter, YouTube, and Instagram, communication researchers must (1) explore this new messaging landscape, (2) leverage its opportunities to advance communication theory, and (3) critically examine its ethical and societal implications (e.g., [83]).

4.4. Strengths and Limitations. The strengths of our study include the following: First, we controlled how much attention people have available to allocate to the messages (trash-counting vs. free-viewing) and what types of messages they can be exposed to (low vs. high emotional salience). Compared to other studies that are more focused on naturalistic environments (where there is eye-tracking or potential for message exposure but no control over the messages) or strictly lab-based work (where people are forced to read/see every message), our study holds a middle ground. Finally, we added methodological innovations (e.g., using VR-based eye-tracking and generative AI to create messages) and combined them with integrative theorizing (e.g., connecting the exposure–reception–retention chain and manipulating emotional message factors).

However, there are still limitations to this study. First, we purposefully limited the strength of the emotional message manipulation because we did not want to cause any unintentional emotional harm to the participants. This could have backfired, leading to small or statistically insignificant effects in the comparison of less versus more emotionally salient billboard images as well as the interaction between billboard emotionality and the driving task. Therefore, future studies should either include stronger manipulations of billboard emotionality or larger sample sizes to achieve higher statistical power, particularly for more subtle interaction effects between stimulus-driven (billboards' emotional salience) and task-driven demands (free-viewing vs. trash-counting instruction).

Moreover, in this study, free recall and recognition were included as primary outcome variables and a standard way of testing memory. However, future research could incorporate other memory measures, such as cued recall or implicit memory tests, which could provide additional insights into how messages are retained in memory—even outside of conscious awareness or when memories are not actively retrievable. In addition, while VR and eye-tracking methods have advanced far, more objective measurements such as neural activity recordings such as EEG could further add to our understanding of how attention, exposure, and message factors interact to influence memory. Additionally, while the current study focused on trash-counting as the distracted condition (i.e., task type), future research could benefit from incorporating real-life distractors such as in-car conversations, music, or unexpectedly and spontaneously appearing objects with varying salience or response demands, like pedestrians crossing and distracting your way, which would allow for an in-depth understanding of how dynamic elements within the real-life environment impact cognitive processing and attention allocation. Another point worth noting is the fact that the VR itself could be improved. Although participants were generally satisfied and positively surprised by the realism and reported little distraction due to VR equipment or adverse effects, it is clear that both the equipment and the fidelity of the environment could be improved further, perhaps even so much that the equipment becomes unnoticeable and the boundaries between reality and VR blur even more.

Finally, to further enhance the ecological validity of our findings, future research should also consider including more complex driving challenges such as the need to navigate, interact with the traffic, or respond to changing road conditions. This inclusion would provide further insights into interpreting our results in more realistic and high-demand driving scenarios. These enhancements would not only allow for testing the robustness of our findings across different types of common driving interruptions but also strengthen the practical applicability of our research and offer a more nuanced understanding of attention allocation.

5. Summary and Conclusions

For the messages to have an effect, ensuring that people are actually exposed to the messages and pay attention to them is the key. In summary, our study weaves a coherent theoretical throughline that connects exposure, reception, and retention in communication. By bridging the gap between these links, we can not only examine the causal influence of theorized variables—emotional attention and distraction—empirically but also provide a flexible paradigm for future studies on message effects in health communication, politics, or advertising.

Data Availability Statement

The data that support the findings of this study are openly available at https://github.com/nomcomm/vr_billboard_e.

Disclosure

This manuscript was previously made available as a preprint on bioRxiv: doi:10.1101/2024.07.19.604208 [84].

Conflicts of Interest

The authors declare no conflicts of interest.

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