wound sites and suggested that an exocytosis-mediated local drop in membrane tension might recruit ESCRT proteins (*4*). Thus, plasma membrane repair may involve the concerted action of Ca^{2+}-regulated lysosomal exocytosis, up-regulation of endocytosis, and ESCRT recruitment (see the figure). This scenario is consistent with the frequent detection of rapid Ca^{2+}-dependent lysosomal exocytosis in cells permeabilized by various mechanisms (*7*, *11*, *12*) and with the finding that the inhibition of lysosomal exocytosis blocks plasma membrane repair (*7*, *13*). Notably, the lysosomal enzyme acid sphingomyelinase, when released extracellularly by wounded cells, can be sufficient for promoting endocytosis and plasma membrane repair (*9*). With the exciting possibilities now offered by advanced imaging techniques, the next step should be to define the spatiotemporal relationship of membrane wounding with lysosomal exocytosis, endocytosis, and ESCRT recruitment. If this can be achieved, it would greatly facilitate the challenging process of deciphering how each of these pathways contributes to lesion removal. This is important because a comprehensive understanding of the plasma membrane resealing mechanism may reveal steps amenable to therapeutic intervention, as illustrated by the recent report of enhanced muscle repair by in vivo expression of lysosomal acid sphingomyelinase (*14*).

ESCRT proteins also promote repair of nanoscale lesions in the endolysosomal network and the nuclear envelope, by mechanisms that are still poorly understood but that may not involve vesicle budding (*15*). Surprises certainly lie ahead as the fascinating roles of ESCRT proteins in membrane remodeling are better understood along with their relationship, if any, to wound-induced membrane trafficking events. ■

REFERENCES AND NOTES

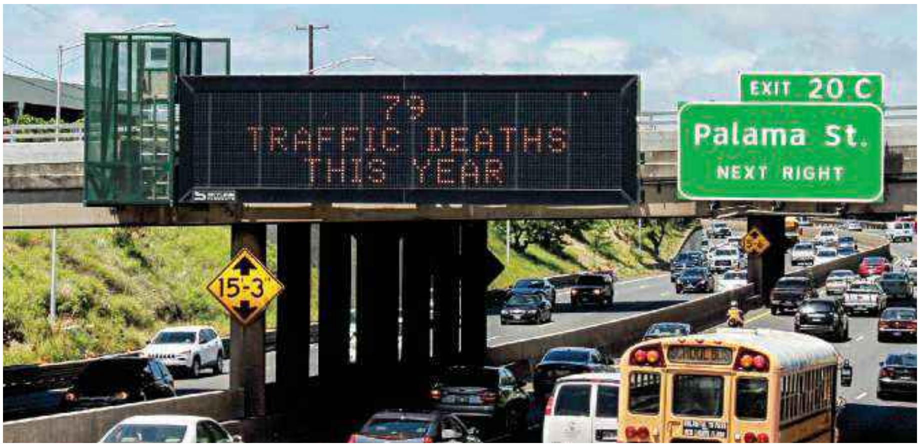
1. A. T. Ritter *et al.*, *Science* **376**, 377 (2022).
2. M. Vietri, M. Radulovic, H. Stenmark, *Nat. Rev. Mol. Cell Biol.* **21**, 25 (2020).
3. J. Schöneberg, I.-H. Lee, J. H. Iwasa, J. H. Hurley, *Nat. Rev. Mol. Cell Biol.* **18**, 5 (2017).
4. A. J. Jimenez *et al.*, *Science* **343**, 1247136 (2014).
5. L. L. Scheffer *et al.*, *Nat. Commun.* **5**, 5646 (2014).
6. V. Idone *et al.*, *J. Cell Biol.* **180**, 905 (2008).
7. N. W. Andrews, M. Corrotte, *Curr. Biol.* **28**, R392 (2018).
8. D. Keefe *et al.*, *Immunity* **23**, 249 (2005).
9. C. Tam *et al.*, *J. Cell Biol.* **189**, 1027 (2010).
10. J. A. Lopez *et al.*, *Blood* **121**, 2659 (2013).
11. C. S. Ferranti *et al.*, *J. Cell Biol.* **219**, e201903176 (2020).
12. C.-L. Forestier, C. Machu, C. Loussert, P. Pescher, G. F. Späth, *Cell Host Microbe* **9**, 319 (2011).
13. M. Encarnação *et al.*, *J. Cell Biol.* **213**, 631 (2016).
14. D. C. Bittel *et al.*, *J. Clin. Invest.* **132**, e141295 (2022).
15. K. P. Bohannon, P. I. Hanson, *Curr. Opin. Cell Biol.* **65**, 122 (2020).

ACKNOWLEDGMENTS

N.W.A. has consulted for Casma Therapeutics, Inc.

10.1126/science.abp8641

PHOTO: HDOT



A dynamic message sign displays traffic deaths above the H-1 Freeway on the Liliha Street overpass in Hawaii.

BEHAVIORAL SCIENCE

How safe are safety messages?

Highway fatalities increased in response to certain messages

By **Gerald Ullman** *and* **Susan Chrysler**

With 1.35 million people killed in road crashes worldwide each year (*1*), highway agencies search for ways to reduce traffic deaths and injuries, including encouraging safer driving behaviors. Electronic dynamic message signs (DMSs) (see the photo) are viewed as highly effective devices for communicating traffic safety messages directly to the driving public with the goal of improving road safety (*2*). However, the actual effects of such DMS messages on road safety have never been evaluated in a rigorous manner. On page 370 of this issue (*3*), research by Hall and Madsen suggests that, contrary to expectations, displaying traffic fatality numbers in traffic safety messages on DMSs is associated with an increase in crashes downstream.

Beginning in 2012, the Texas Department of Transportation (TxDOT) began posting traffic safety messages for 1 week per month on its statewide network of nearly 900 DMSs. Messages consisted of a traffic safety slogan (e.g., DON'T DRINK AND DRIVE) and the cumulative number of traffic fatalities that year on Texas roadways (XXX TRAFFIC DEATHS ON TEXAS ROADWAYS IN 2012). These messages were displayed when the signs were not used for conveying other transportation-related information about incidents, roadwork, or special events. The rest of the month, fatality information was not displayed.

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Hall and Madsen compared crashes downstream of DMSs across the state during periods when traffic safety messages with fatality numbers were being displayed versus not being displayed. To control for other possible factors influencing their results, they also compared crashes on those same roadway segments before the fatality message campaign began and on roadway segments upstream of the DMSs. They concluded that the display of traffic safety messages with fatality numbers resulted in a 1.35% increase in traffic crashes up to 10 km downstream of the DMSs.

Hall and Madsen contend that these results suggest that messages with fatality numbers are overly salient to drivers. They do not discuss the valence of emotions that fatality messages induce, but instead focus on their salience in the working memory of drivers leading to cognitive distraction, which leads to driving errors. The finding seems inconsistent with other research that has found that the use of fatalities and other statistics in traffic safety campaigns is mostly ineffective in influencing driver attitudes or behaviors, in large part because of "optimism biases" held by most drivers regarding their abilities to operate a vehicle and avoid becoming involved in a fatal crash (*4*, *5*). However, because the effect of the fatality messages was greater in urban areas, the issue may be one of excessive salience or of some cognitive overload. Given the greater baseline cognitive demand of multilane urban freeways compared with rural highways, the additional cognitive load induced by fatality messages may be enough to push some drivers beyond their attentional capacity. Such effects of attentional overload have been demonstrated in driving simulations, naturalistic driving studies, and closed-course evaluations (*6*).

Research on the effects of emotional distraction upon the driving task is limited, but there are a few studies that support the hypothesis. This research often relies on self-report and surveys of past driving incidents, making causal attributions difficult. Laboratory and simulation studies must attempt to induce a particular emotion to study its effect. One simulator study of the effects of auditory messages of positive and negative emotion (*7*) showed that negative words reduced driving speed and worsened lateral control compared with positive words. Evoked response potentials used to assess the allocation of attentional resources across tasks showed that positive and negative stimuli were processed differently. Similar studies suggest that negative billboard images can degrade driving performance (*8*, *9*). One simulator study showed that induced happiness and anger each caused more driving errors compared with neutral and fear conditions, but subjective workload was similar across the affective states (*10*). Conversely, other studies suggest that drivers will modulate their glances to billboards based on the situational demands of the driving task (*11*, *12*). Whether the same modulation occurs for messages presented on DMSs during times of high attentional demand is unknown.

Another plausible hypothesis for the results obtained by Hall and Madsen is that it is the overall design of the traffic safety messages, including fatality numbers, which collectively contributes to an information overload situation that has adverse effects upon driving behavior. Messages must be limited in length and formatted to ensure that motorists can quickly read and correctly process the information presented during limited viewing time. Guidelines and regulations have been developed on how to best design DMS messages reporting things like traffic incidents, special events, and roadwork activities (*13*). Similar guidance does not yet exist for traffic safety messages. These messages are often unclear in terms of how drivers should respond to the information. It has commonly been assumed that drivers simply read and then quickly disregard messages that they deem unnecessary. However, the results of Hall and Madsen suggest that drivers may continue to try and assess how they are supposed to use that information for a much longer period of time after reading the message.

Although not something that Hall and Madsen could explicitly test with the Texas dataset, this hypothesis would help explain why a message containing fatality numbers could impede a driver's cognitive abilities and adversely affect their driving performance but not influence their attitudes or conscious driving behaviors. This hypothesis would also suggest that similar effects would be expected when using other numbers in traffic safety messages, such as the number of speeding tickets issued, the percentage of crashes involving impaired motorists, etc. (again, a hypothesis that Hall and Madsen could not test with the existing Texas dataset). Although not necessarily in response to the Hall and Madsen results, it should be noted that the US Federal Highway Administration in 2021 discouraged the use of fatality numbers and other statistics in traffic safety messages displayed on DMSs (*14*).

The crash data presented by Hall and Madsen clearly demonstrate a safety effect of showing fatality numbers on DMSs. However, the mechanism for this safety effect is not clearly elucidated by the data presented in the paper. Additional analyses regarding crash types and documented causal factors in the crash reports might yield more insights. For example, the authors treated all types of crashes as equal and only separated single-vehicle from multiple-vehicle crashes. The assertion that emotional salience caused distraction would predict a pattern of crash types that would be the result of distraction, such as rear-end crashes resulting from delayed response to a slowing lead vehicle. Examining the pattern of specific crash configurations would be a stronger test of the distraction explanation posited by the authors. ■

REFERENCES AND NOTES

1. National Center for Injury Prevention and Control (NCIPC), "WISQARS™ – Web-based Injury Statistics Query and Reporting System" [Centers for Disease Control and Prevention (CDC), 2018]; www.cdc.gov/injury/wisqars.
2. Federal Highway Administration (FHWA), "Manual on Uniform Traffic Control Devices (MUTCD)" [US Department of Transportation (US DOT), 2009].
3. J. D. Hall, J. Madsen, *Science* **376**, eabm342 (2022).
4. B. Elliot, "Road Safety Mass Media Campaigns: A Meta Analysis," report no. CR 118 (Federal Office of Road Safety, Australia, 1993).
5. N. Guttman, *Accid. Anal. Prev*. **84**, 153 (2015).
6. M. A. Regan, J. D. Lee, K. L. Young, Eds., *Driver Distraction: Theory, Effects, and Mitigation* (CRC Press, 2008).
7. M. Jeon, B. N. Walker, J.-B. Yim, *Transp. Res. Part F Traffic Psychol. Behav*. **24**, 197 (2014).
8. H. E. K. Walker, L. M. Trick, *Safety Sci*. **115**, 121 (2019).
9. A. Megías, A. Maldonado, A. Cándido, A. Catena, *Accid. Anal. Prev*. **43**, 813 (2011).
10. M. Chan, A. Singhal, *Safety Sci*. **72**, 302 (2015).
11. K. L. Young, A. N. Stephens, D. B. Logan, M. G. Lenné, *Appl. Ergon*. **60**, 136 (2017).
12. J. S. Decker *et al*., *Traffic Inj. Prev*. **16**, 234 (2015).
13. C. L. Dudek, "Changeable Message Sign Operation and Messaging Handbook," report no. FHWA-OP-03-070 (FHWA, US DOT, 2004).
14. M. R. Kehrli, "Uses of and Non-Standard Syntax on Changeable Message Signs," MUTCD Official Ruling no. 2(09)-174(I) (FHWA, US DOT, 2021).

10.1126/science.abq1757

ELECTROCHEMISTRY

Electrifying membranes to deliver hydrogen

An electrochemical membrane reactor enables efficient hydrogen generation

By **Arthur J. Shih** *and* **Sossina M. Haile**

The developed world has had a vacillating interest in hydrogen (H_2) as the green fuel of the future. Today, the interest is being renewed as the climate crisis becomes increasingly evident (*1*). A key challenge with hydrogen, presuming that it can be generated by using sustainable electrical power, is its economical delivery. The daunting cost of installing a hydrogen infrastructure has been a major driver behind the decision of policy-makers in the United States and elsewhere to put the hydrogen effort on hold (*2*). On page 390 of this issue, Clark *et al.* (*3*) address head-on the hydrogen infrastructure need by exploiting electrochemical membrane reactors to strip hydrogen from more convenient carriers, including ammonia (NH_3), methane (CH_4), and biomass. These fuels could potentially be delivered to a point of need by using an existing infrastructure, where they could then be converted to hydrogen for use in fuel cells.

The concept of using liquid or easily liquified hydrogen carriers to fulfill hydrogen delivery needs has gained traction in recent years (*4*–*6*). Ammonia as the carrier is attractive because the cycle is entirely carbon free; whereas methane is attractive because the locally produced carbon dioxide can potentially be sequestered; and biomass is attractive because if deployed alongside sequestration, it results in a carbon-negative cycle. Among the reactor types available for extracting hydrogen from hydrogen-bearing compounds, electrochemical membrane reactors based on proton ceramic electrolytes offer distinct advantages. Such reactors combine thermochemical

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Science, 376 (6591), • DOI: 10.1126/science.abq1757

Science (ISSN 1095-9203) is published by the American Association for the Advancement of Science. 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.