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Speeding through the pandemic: Perceptual and psychological factors associated with speeding during the COVID-19 stay-at-home period

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ABSTRACT

During the COVID-19 stay-at-home period there were observed increases in both the percentage of cars engaged in extreme speeding, and the percentage of cars traveling below the speed limit. These changes have been attributed to unusually low traffic volume during the stay-at-home period. We develop a novel theoretical account, based on existing empirical research, of perceptual and psychological processes that may account for changes in speeding behavior under low traffic volume conditions. These include impaired ability to accurately perceive and control speed due to change in visual information, decreased salience of certain norms about socially appropriate speeds, lower perceived risk of speeding, and increased boredom leading to risk-taking behaviors. Further, we consider that individual attitude functions may account for the observed split in speeding behavior.

1. Introduction

Motor vehicle crashes and fatalities typically decrease during periods of economic hardship (Afroz et al., 2012; Blower et al., 2019). However, the COVID-19 pandemic and associated stay-at-home order has been associated with increases in the incidence of certain crash types, most notably fatal, single car crashes (Doucette et al., 2021). Further, changes in speeding behavior have been observed: the COVID-19 stay-at-home order in Connecticut was associated with increases in the percentage of cars engaged in extreme speeding (i.e. more than 20mph over the posted speed limit) and the percentage of cars traveling below the speed limit, but a decrease in the percentage of cars traveling fewer than 20mph over the speed limit (e.g., 66-84mph in a 65mph zone) (Shapiro et al., 2021). These changes are attributable to the decrease in traffic volume during the COVID-19 stay-at-home period, rather than seasonality; early reports indicate a 40 to 60% reduction in VMT (vehicle miles traveled) associated with the COVID-19 pandemic (Agrawal et al., 2020; Doucette et al., 2021; Shapiro et al., 2021).

Changes in observed speeding pose a unique challenge: it appears that a split in the driving population exists, such that some drivers became more cautious during the stay-at-home period, accounting for the increase in the percentage of cars traveling below the speed limit, whereas others drove more recklessly, accounting for the increase in the percentage of cars engaged in extreme speeding. However, it is not well understood how or why the behavior of any individual driver might change under the low-volume conditions associated with the COVID-19 stay-at-home order. Provisional answers may be gleaned from research on the perceptual and psychological factors that influence driver behavior under normal driving conditions. It is commonly claimed that 90% of the information drivers use to control vehicle speed and heading is visual; while the specific “90%” claim is difficult to verify, is it widely accepted that drivers guide their behavior through the detection of visual information (Sivak, 1996). Thus, it may be possible to gain insight into expected or observed changes in driver behavior during a pandemic by assessing changes in the visual information available to drivers. To this end, we draw on seminal work by Gibson and Crooks (1938); Gibson’s (1966); Gibson’s (1979) later theories of ecological optics and affordances, and more recent work in the Gibsonian tradition. Foundational to the Gibsonian approach is the notion that organisms directly perceive and act on environmental affordances - loosely, opportunities for action that exist by virtue of specific organism-environment relations – that are specified by visual and other sensory information (Gibson, 1966). Because the COVID-19 pandemic has been associated with steep declines in traffic volume (Doucette et al., 2021; Shapiro et al., 2021), we primarily consider the impacts of decreased traffic volume on the available visual information, and relatedly, the affordances available to

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drivers. With atypically low traffic volume, the opportunities for action available drivers are expanded; how drivers behave in light of these changed conditions may depend on a number of social and motivational factors. On the basis of existing research, it appears that changes in the available visual information concomitant with lower traffic volume may be associated with impairments in drivers' ability to perceive and control their speed, absence of information about socially appropriate speeds (i.e., how others are driving), lower perceived risk of driving faster, and increased boredom leading to risk-taking behaviors.

2. Perceptual factors

Psychological models of driver behavior have historically been influenced by, and reciprocally influence, models of human locomotion (Gibson and Crooks, 1938). Whereas locomotion is guided by visual and haptic (or proprioceptive) information, driving relies almost entirely on visual information. This is of particular importance as it is known that, during locomotion, haptic or proprioceptive information can play a role in the perception of speed and distance traveled (Turvey et al., 2009, 2012; Chrastil and Warren, 2014). Lacking these, drivers are almost entirely dependent on visual information for speed regulation; vestibular information (i.e. that from the inner ear) plays only a minor role in perception of speed during driving (Lappe et al., 1999). Of course, information regarding speed is available through a vehicle's speedometer. In everyday driving, however, drivers may not regularly check their speedometer, but instead rely on what feels safe or appropriate for prevailing conditions; experimental evidence suggests that speedometer glances are relatively short and infrequent, especially among more experienced drivers (Lee et al., 2006; Lehtonen et al., 2020). In on-road experiments, it has been observed that drivers spend 0.7% to 3% of the time looking at the speedometer or instrument panel (Lansdown, 2003; Recarte and Nunes, 2003), with a frequency of 0.36 to 1.49 glances per minute (Lansdown, 2003). At 65mph, a driver might therefore travel 0.72 to 3 miles between instrument panel glances. Perception of speed, safety, and appropriateness, then, are derived primarily through variables present in *optic flow* (Gibson, 1979; Lappe et al., 1999)—the transformations of the visual field that distinguish self-motion from the motion of external objects.

Two key variables present in optic flow are particularly important for control of vehicle speed: optical edge rate, and tau, specifying time-to-collision. The first, optical edge rate, refers to "the rate at which local discontinuities cross a fixed point of reference in the observer's field of view" (Larish and Flach, 1990; p 295), where local discontinuities may be objects in the environment, other vehicles, or elements of the ground texture. Optical edge rate may be contrasted with global flow rate, which scales with the velocity of forward motion independent of ground texture or objects in the environment (Larish and Flach, 1990). Put quite broadly, lower optical edge rate and lower global flow rate are both commonly associated with slower speeds. However, lower optical edge rate also occurs in very sparse environments. Decreased traffic volume could therefore lead to reduced optical edge rate. Further, optical edge rate, but not global flow rate, is a primary source of information by which the speed of self-motion is perceived (Larish and Flach, 1990; Andersen et al., 1999). If it is in fact the case that decreased traffic volume is associated with lower optical edge rate, this may result in systematic underestimation of speed by drivers. This effect has been demonstrated in both lab and field settings (Denton, 1980; Warren, 1982). Despite this, it is not currently known if or how drivers may adapt and come to use other sources of visual information to compensate for impacts of decreased traffic volume on optical edge rate. With low traffic volume, optical edge rate information generated by the ground texture and road markings may still be used (Lidestam et al., 2019). Further, there is some evidence that global flow rate may substitute for optical edge rate in situations where edge rate is deemed unreliable (Dyre, 1997; Ballard et al., 1998). However, decreased traffic volume could also reduce the magnitude of motion parallax, leading to underestimation of speed (Dyre et al., 2006). Given this, with fewer other vehicles on the road, drivers may be missing important external referents for accurately perceiving their own speed. On the whole, we would expect these changes in optical information to result in underestimation of speed by drivers, potentially leading to speeding.

The second key variable, tau, is the inverse of the rate of optical expansion of angles in the visual field, and specifies time-to-collision (Lee, 1976). Objects in an environment subtend a certain optical angle. The change in that optical angle over time, as occurs through motion of the object or self, is termed optical expansion or contraction as appropriate. The rate of an object's optical expansion (i.e., the expansion rate divided by optical angle), in particular, plays a key role in speed management and braking; drivers are able to perceive with quite high accuracy whether or not they will collide with an object or vehicle ahead of them, and make time-to-collision estimates, on the basis of optical expansion rate (Lee, 1976; Rio et al., 2014). Like optical edge rate, use of optical expansion rate reveals the importance of external referents in the perception of one's own speed. However, where other vehicles passed by a driver provide an external referent used for speed perception through optical edge rate, the presence of a lead vehicle provides a referent through optical expansion or time-to-collision. In normal driving, a lead vehicle necessarily constrains speed to some extent, as the following vehicle cannot driver faster than it without risking a collision. In addition to this, it also creates visual information – optical expansion or contraction – that reflects the relation between the speeds of the leading and following vehicles. The environmental affordances for, or constraints on, a vehicle's movement and associated visual information are therefore concomitant; visual information is generated by real relations among objects in an environment, and specifies to a perceiver what actions may be taken in that environment. When many vehicles share a road, each vehicle creates visual information that supports other drivers' accurate speed perception and management. With fewer vehicles on the road than normal, optical information is changed in such a way that drivers perceive the road as affording faster travel.

Additionally, the changes in perceptual variables associated with lower traffic volume during the COVID-19 pandemic parallel some differences between urban and rural driving. Namely, rural driving is typically associated with relatively lower visual demand, affecting driving behaviors and drivers' eye movements (Lansdown, 2003; Engström et al., 2005; Chapman and Underwood, 1998). In comparisons of urban and rural driving it has been found that higher visual demand in driving is associated with lower speeds (Engström et al., 2005), and that lower visual demand is associated with higher speeds (Antonson et al., 2009). Similarly, drivers in tunnels, which are characterized by very low visual demand, have been shown to underestimate their speed, leading to increased speeding (Wan et al., 2018). Tunnel sidewall markings, which may increase optical edge rate, have been shown to reduce this effect (Wan et al., 2018). We may then expect that lower visual demand caused by decreased traffic volume would be associated with higher speeds.

3. Risk and boredom

Perceptions of risk might also be challenging in low traffic volume conditions. Early field-theoretic models of driver behavior suggested that drivers can perceive, on the basis of visual information similar to that identified above, a "field of safe travel" – an area in or through which the vehicle may be safely driven (Gibson and Crooks, 1938). The size of the field of safe travel necessarily depends on environmental layout, including the nature and quality of the road, presence of other vehicles and obstacles, and prevailing weather conditions. Relatedly, drivers identify a "minimal stopping zone", which represents the area within which they could stop the vehicle. The perceived risk of a driver's current actions could reflect the relation between the sizes of the field of safe travel and minimal stopping zone: as size of the minimal stopping zone approaches that of the field of safe travel, greater risk is perceived.

Notably, risk is therefore not perceived in reference to absolute units, such as distance or miles per hour, but rather in reference to environmental and behavioral factors; it corresponds to the relation between what actions the environment affords to the driver, and the driver's capabilities to act. Further, although the concepts field of safe travel and minimal stopping zone predate Gibson's later ecological theory and related research, such as that on tau, we expect that they are compatible. A driver might identify, based on tau and other visual information, affordances that are functionally similar to the field of safe travel and minimal stopping zone.

More recent motivational accounts of driver behavior have suggested that drivers seek homeostasis of one or more related variables, such as risk, task difficulty, or challenge (Ranney, 1994; Fuller, 2005). That is to say, drivers adjust their behavior so as to maintain a more-or-less constant and acceptable level of perceived risk, challenge, or some other variable. There is not broad agreement on which specific variable drivers prioritize, and the preference for or attention given to one over others may depend on individual factors. However, because psychological variables such as risk are managed, and not physical variables like speed in itself, these models account for some of the flexibility drivers exhibit in different environments or situations. A combination of field-theoretic and motivational models may help explain changes in driver behavior under low traffic volume conditions. When fewer cars are on the road, a driver's field of safe travel is expanded. Given that perceived risk is a function of the relation between the field of safe travel and the minimal stopping zone, maintaining a constant level of perceived risk would entail expanding the minimal stopping zone - that is, relaxing the constraint on speed and driving faster. Changes in the environment are thereby met with changes in behavior in order to achieve homeostasis of a psychological variable. There are several disadvantages to this response. Speed is, in general, positively related to crash risk and severity (Pei et al., 2012; Aarts and van Schagen, 2006). Additionally, there may be secondary perceptual or psychological effects. It has been found that adaptation to moving at a high speed causes systematic underestimation of speed when it is decreased (Hietanen et al., 2008). A driver who acclimates to a higher speed on a highway, for example, may then tend to underestimate their speed when transferring onto an off ramp or local road. Similar effects occur with changes in gaze fixation distance: when one switches from a distant point of fixation to a nearer one while in motion, speed is typically underestimated (Yotsutsuji and Kita, 2010).

Finally, lower traffic volume may cause increased boredom among drivers, potentially resulting in increased speeding or other unsafe behaviors as coping strategies. Boredom here is defined as "the aversive experience of having an unfulfilled desire to be engaged in satisfying activity" (Fahlman et al., 2013, p. 69), and is understood to occur in situations where stimulation or information is sparse, monotonous, or meaningless. In driving, it is associated with low traffic volume, routine trips, slower speeds, and use of cruise control or other kinds of automation (Steinberger, 2018). To cope with boredom drivers may adopt any of a number of strategies, which are characterized as either "approach strategies" or "avoidance strategies" (Steinberger et al., 2017). Approach strategies are those which re-engage the bored driver in the driving task, and can include changing lanes, aggressive driving, and speeding. Avoidance strategies tend to reduce task engagement further, and may include phone use, day-dreaming, and listening to music; these are more typically associated with distraction and taking one's eyes off the road (Steinberger et al., 2017). Secondary task engagement while driving is associated with reduced speed (Young and Regan, 2007). Specifically, phone use is associated with both reduced speed (Iio et al., 2021) and increased time to recover speed lost by braking (Jamson et al., 2004). Boredom may therefore lead to either increased or decreased speed, contingent on individual drivers' preference for approach or avoidance strategies. However, it is not presently known why or when drivers might adopt one coping strategy over others. This too may be associated with individual factors; Zuckerman (2007) suggests that individuals high on sensation-seeking are more likely to compensate for boredom with risky driving. Nonetheless, both approach and avoidance strategies are likely to increase risk. Approach strategies such as speeding are directly associated with increased crash risk (Aarts and van Schagen, 2006), while avoidance strategies which involve distraction are more likely to result in heading errors, leading to lane keeping errors (Engström et al., 2005).

4. Social and motivational factors

The information that other moving vehicles convey not only provides perceptual support for monitoring one's own speed adequately, but it also provides *social* support for maintaining a given speed; it allows drivers to ground their actions in the context of what is socially acceptable behavior. Descriptive norms convey what speed other people are driving, whereas injunctive norms convey "ought" information about what other people, societal regulations, or laws imply drivers *should* do (Cialdini et al., 1991). Research suggests that descriptive norms in particular can affect driving speed. For example, young drivers' beliefs about how fast their friends drive have been found to strongly predict their own speeding (Møller and Haustein, 2014). Moreover, interventions that lower the believed speed of other drivers using dynamic signage can reduce driver speeds (Van Houten and Nau, 1983). But in most daily circumstances, the perception that one's own speed is within a normal range and is unlikely to lead to negative societal consequences (a speeding ticket, or angry honks) comes from the direct influence of a heuristic to drive within the normal flow of other drivers.

When normative information is unavailable to guide behavior, driving speed will likely be more strongly influenced by individual differences in the motives inherently underlying people's driving behavior, and the attitude functions which these behaviors satisfy (Katz, 1960). Attitude function approaches to predicting behavior suggest that individuals' attitudes towards different objects or behaviors serve different attitude functions (Katz, 1960; Shavitt, 1990), and that attitude functions may vary across different situations (Marsh and Julka, 2000; Julka and Marsh, 2005). For example, an individual may hold positive attitudes about speeding insofar as it serves the attitude function of utility. However, certain attitude functions may become more or less relevant under conditions of substantially reduced traffic volume; in a driving environment that evokes few social pressures, provides less information about others' behavior, and has no "audience" of other drivers, motivation to drive slower or faster to convey a certain impression on others, or to avoid negative consequences from others' reactions, is likely minimal.

Other intrinsic motives might instead play a role. Research suggests that the same attitude topic, such as attitude toward personally speeding, can serve different functions for given individuals (DeBono, 1987; Katz, 1960; Maio and Olson, 2000; Shavitt, 1990; Smith et al., 1956). For some individuals, attitudes surrounding driving may meet certain needs for status and superiority—getting ahead of, cutting in front of, and showing disdain for other drivers. Under low density situations, such motives are likely to be less evident than other functional bases of driving attitudes. For some individuals, utilitarian and hedonic functions of speeding would involve practical benefits and costs of driving slower versus faster, including the potentially pleasurable experience of going fast, or the boredom of driving slowly. For other individuals, driving behaviors could serve the function of expressing one's personal values, such as about energy conservation; a driver of a hybrid vehicle might strive to get positive feedback from his/her energy display that suggests optimal driving, or consciously try to conserve gas by minimizing hard braking and rapid accelerations. In extreme cases, risky driving behavior may reflect depression or suicidality, which may be increased during a pandemic. Specific to the COVID-19 pandemic, slower driving may reflect a general concern for others' safety, or respect for and adherence to rules that are intended to promote safety. It may also reflect a concern for one's own health and well-being, insofar as slower driving decreases the risk of interacting with others (e.g., police at a traffic stop, EMTs at a crash). Some support for the notion that drivers tend to vary in the functions that underlie their attitudes toward speeding comes from research finding that drivers do vary in driving styles—aggressive, cautious, or defensive for instance (Sagberg et al., 2015). Accordingly, a motive-based account for driving tendencies would suggest that under an unusual drop in traffic volume, driver responses may fairly diverge as the relative weight or relevance of different individual attitude functions change.

5. Conclusions and limitations

On balance, existing empirical research suggests that decreased traffic volume is likely to result in impairments in drivers' ability to accurately perceive, and thus control, their own speed. Three primary processes are likely at play. First, in low traffic volume conditions drivers lack visual information that they would typically use to detect their own speed. Systematic underestimation of speed, and thus speeding, are possible results. Second, it has been suggested that drivers seek homeostasis of perceived risk. With fewer cars on the road, speeding is likely to be perceived as less risky, as any given car's field of safe travel is expanded. If this is in fact the case, it would entail more speeding in order to maintain the desired or acceptable level of risk. Finally, low traffic volume is associated with increased boredom. Drivers may adopt a number of strategies to deal with boredom. Many of these, such as speeding, aggressive driving, and phone use, are associated with increased risk. A summary of factors considered and their anticipated effects on speeding is given in Table 1.

It should be noted that, while this assessment draws on the work of Gibson (1966); Gibson (1979), which lead to the discovery of optical variables such as optical edge rate and time-to-collision, our use of terminology is not wholly consistent with Gibson. For example, we have described certain variables as being involved in speed perception. However, speed, at least in terms of metrical units such as miles per hour, is not in itself perceptible (Gibson, 1979). Organisms regulate their behavior with regard to the affordances, or possibilities for action, in an environment, which are perceived directly. Perception is then of action-relevant and action-scaled properties (Gibson, 1966, 1979). A driver might directly perceive, for example, that they will or won't make a traffic light, and not that they are so many meters away from the light, and traveling at so many miles per hour. These perceptions of affordances – of what actions may be taken in a given situation – necessarily hinge not only on the environment but also on the driver's capabilities for action: their driving aptitude, the acceleration or braking performance of their vehicle, and so on. In this way, affordances inhere in the relation between driver and environment. In driving, however, behavior must be regulated both with regard to affordances and with regard to more abstract rules, such as speed limits, that set certain constraints. Regulation of behavior according to an abstract rule or variable requires either a tool, such as a speedometer, or the individual calibration over time of that which is immediately perceived (i.e., affordances) with that which must be ascertained (i.e., speed in miles per hour). Thus, while we have described factors such as lower optical edge rate as affecting speed perception, it may be more accurate to say that they affect the mapping of perceptions of environmental affordances onto more abstract variables. Further, we would not suggest that changes in perceptual information result in drivers perceiving that a road affords speeding, as speeding exists only in relation to traffic rules that are not present in optic flow in the manner of optical edge rate and time-to-collision. Rather, it may be that drivers perceive a road as affording safe travel at such-and-such a rate in the way that a pedestrian might perceive a slippery patch of sidewalk as affording running over, walking over, or neither. That is, the perception occurs first in terms of "What actions can I take?", and for the driver only later in terms of "How many MPH/KMPH?" and "Is it legal?".

Table 1
Factors considered and anticipated effects on motor vehicle speeds.

Factor	Effect on Speed
Decreased optical edge rate	Increase
Absence of time-to-collision information	Increase
Decreased motion parallax magnitude	Increase
Lower visual demand	Increase
Lower perceived risk	Increase
Increased boredom	Increase OR Decrease, dependent on coping strategy
Lack of social normative information	Increase OR Decrease, dependent on individual attitudes or motivations

The above perceptual factors suggest that decreased traffic volume ought to be associated with increased speeding. Indeed, some research has found increases in speeding in conjunction with decreased traffic volume in the early months of the COVID-19 pandemic (Katrakazas et al., 2020; Lee et al., 2020; Shapiro et al., 2021). Absent unique effects from the COVID-19 pandemic, we would expect lower traffic volume to lead to increased speeding for most drivers. However, while there was an observed increase in extreme speeding during the COVID-19 stay-at-home period, there was also an increase in the percentage of cars traveling below the speed limit (Shapiro et al., 2021). This divergence likely reflects differences in individual attitudes or motivations that affect the impact of any of the above-mentioned perceptual factors on actual driving behavior. It may be the case that, lacking perceptual information that supports accurate speed perception and normative information that creates situational pressures, drivers' different motivational tendencies are revealed, or their effects are amplified. For example, drivers prioritizing utility, in the sense of reaching their destination faster, may be more likely to engage in speeding. Drivers prioritizing value expression, which may, for example, include expression of concern for the well-being of others, might instead drive more cautiously. Others prioritizing health and safety may also drive slower to avoid potential interactions with police that do not allow for social distancing. Further empirical research is required to examine the mechanisms by which conditions unique to the COVID-19 period affect speeding.

These conclusions naturally warrant empirical evaluation through simulator, road video, or on-road studies. This is especially relevant as many of the theoretical constructs applied were not developed with driving in mind, and their application here is novel. For example, the role of optical edge rate in speed perception has primarily been explored with reference to ground texture. Controlled studies are therefore required to determine whether changes in traffic volume can produce change in optical edge rate sufficient to affect speed perception, and whether drivers in low volume conditions instead use other visual information to determine their speed. These may be conducted in driving simulators where driver control is required, or else with road video where increased verisimilitude is desirable. Multiple experiments are likely required to establish the specific roles of optic flow variables in driver speed perception under a variety of traffic volume, visibility, road type, and other conditions; through these, it may be possible to develop the present theoretical account into a robust mathematical model. While we expect that changes in perceptual information resulting from lower traffic volume during the COVID-19 pandemic should result in underestimation of speed and increased speeding, it is not clear if these changes can account for the observed increase in extreme speeding. Therefore, determining the magnitude of perceptual effects on speed perception and speeding behavior is of great concern. Additionally, the role of attitudes and motivations in particular warrants further empirical investigation. Extensive evidence suggests that individual-level factors, such as sensation-seeking and boredom proneness, affect driving behavior under normal circumstances (Jonah, 1997; Dahlen et al., 2005). However, it is not presently known how these effects might differ under unusually low traffic volume. Unique circumstances associated with the COVID-19 epidemic might also introduce new motivations that would not normally impact driver behavior. Some motivations, such as those related to social distancing, may persist even as states reopen and traffic volumes return to normal levels.

Through empirical investigation, it is hoped that this theoretical account leads to the development of interventions to reduce speeding that target either drivers' individual motivations, or the social and environmental context in which those motivations play out. Interventions affecting the perceptual information available to drivers have been validated in some simulator studies. These include transverse strips or herringbone patterns on curves (Ariën et al., 2017), and sidewall markings in tunnels (Wan et al., 2018). Similar approaches, including road markings or physical objects like delineator posts, might be temporarily employed to reduce speeding by increasing optical edge rate while traffic volume remains below normal levels. Other interventions might provide additional information or incentives regarding speed to drivers, as has been attempted with some gamified driving apps (Steinberger et al., 2016). However, the effectiveness of such approaches is uncertain. We anticipate that considerable basic empirical research is required to develop interventions based on the current theoretical account, but are optimistic for the potential to improve roadway safety.

CRediT authorship contribution statement

K.L. Marsh: Conceptualization, Writing - original draft, and Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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