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Speeding in School Zones: Violation or Lapse in Prospective Memory?

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Inappropriate speed is a causal factor in around one third of fatal accidents (OECD/ECMT, 2006). But are drivers always consciously responsible for their speeding behavior? Two studies are reported which show that an interruption to a journey, caused by stopping at a red traffic light, can result in failure to resume the speed of travel prior to the interruption (Study 1). In Study 2 we showed that the addition of a reminder cue could offset this interruption. These studies were conducted in a number of Australian school zone sites subject to a 40 km/h speed limit, requiring a reduction of between 20 km/h and 40 km/h. Motorists who had stopped at a red traffic signal sped on average, 8.27 km/h over the speed limit compared with only 1.76 km/h over the limit for those who had not been required to stop. In the second study a flashing "check speed" reminder cue, placed 70 m after the traffic lights, in the same school zones as those in Study 1 eliminated the interruptive effect of stopping with drivers resuming their journey at the legal speed. These findings have practical implications for the design of road environments, enforcement of speed limits, and the safety of pedestrians.

Keywords: prospective memory, interruption, speeding, road safety, school zones

Prospective memory refers to memory for intended future actions without an explicit prompt (Einstein & McDaniel, 1990, 1996). The importance of prospective memory to everyday functioning has meant that research examining prospective memory is receiving growing interest. This is especially true in the area of prospective memory errors. Prospective memory errors describe situations where individuals forget to perform an intended task. For example, an individual may intend to post a letter during a work break but they may forget to do so. Failure to remember to complete deferred intentions can have serious consequences (McDaniel, Einstein, Graham, & Rall, 2004). Indeed, interruptions to preflight procedures and subsequent prospective memory errors have been shown to contribute to planes crashing (see Dismukes & Nowinski, 2006; NTSB, 1988), and midsurgery disruptions have resulted in physicians leaving instruments or sponges in patients following surgery (Dismukes, 2012; Gawande, Studdert, Orav, Brennan, & Zinner, 2003).

The current article draws upon prospective memory literature to make predictions in a real-world driving context. Specifically, our goal is to examine whether being interrupted by having to stop at signalized traffic intersections (i.e., intersections with traffic lights) within school zones can lead to instances of driver error. This follows Dodhia and Dismukes's (2009) proposition that "interrupting ongoing tasks intrinsically create prospective memory tasks" (p. 74). Around schools, it is common to find variable speed limits as the speed zoning is reduced at times when children are traveling to and from school. Typically, a substantially lower speed limit applies, reducing a general urban speed limit of 50–60 km/h, or a higher speed limit for a major road (e.g., 70–90 km/h or higher), to a school speed limit of 25–40 km/h (e.g., Faulks, Irwin, & Chekaluk, 2011; Kattan, Tay, & Acharjee, 2011; Lazic, 2003). We propose that motorists who are interrupted by signalized traffic intersections may forget to resume traveling at the deferred school zone speed limit upon driving resumption. This proposition is based on the predictions made in the interruptions and prospective memory literature.

Dodhia and Dismukes (2009) posit three features of interrupting tasks that may account for why individuals are vulnerable to forgetting to resume deferred actions. From these predictions we propose that signalized traffic intersections within school zones are well suited to the examination of prospective memory retrieval errors. First, being required to stop at signalized traffic intersections can be relatively abrupt compared with maintaining continuous speeds prior to the interruption. Motorists may therefore have little opportunity to encode the intention to resume traveling at the reduced school zone speed limit. Additionally, when motorists are required to stop at signalized traffic intersections they typically encounter stimuli that further distract and capture attention (e.g., pedestrians outside the vehicle or the radio inside the vehicle). These new task demands occur simultaneously with the interruption, distracting motorists and making explicit encoding of the intention less likely to occur. Consistent with this perspective, a central finding in the literature is that prospective memory suffers when attention is divided by a task that engages central executive resources (e.g., Einstein, Smith, McDaniel, & Shaw, 1997; Marsh & Hicks, 1998; Mcgann, Ellis, & Mulne, 2002).

Second, when the traffic light turns green this new task demand draws attention immediately after the interrupting task ends, so there may be limited time to check the status of, and resume, the

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deferred task of traveling at the reduced school zone speed limit (Holbrook, Dismukes, & Nowinski, 2005; Loukopoulos, Dismukes, & Barshi, 2003). Furthermore, cues in the environment that are associated with this new task (e.g., the green traffic light, other motorists accelerating) may also lead an individual to preference the action of accelerating to faster speeds (i.e., to the speed limit prior to the school zone) over retrieval of the interrupted and deferred task.

Third, immediately following driving resumption there are little to no cues present in the environment to prompt memory retrieval for the deferred task of traveling at the reduced school zone speed limit (Dismukes & Nowinksi, 2006; Dodhia & Dismukes, 2009). In the context of McDaniel and Einstein's (2000) multiprocess framework, external reminders may be expected to confer prospective memory gains (see also memory for goals theory, Altmann & Trafton, 2002). Consistent with this perspective, adding reminder cues (Grundgeiger et al., 2013) and increasing a participant's chances of encountering a cue (Kvavilashvili & Fisher, 2007), have been found to increase prospective memory retrieval performance. Furthermore, enhancing the visual conspicuity of cues (e.g., a flashing cue compared to a cue that is static) has consistently been found to improve prospective memory performance (Chung & Byrne, 2008; Dodhia & Dismukes, 2009; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; Loft, Smith, & Bhaskara, 2011; Loft, Smith, & Remington, 2013; Nevo et al., 2010; Roper, Thoresen, Tziotis, & Imberger, 2006; Rummel, Boywitt, & Meiser, 2011; Trafton, Altmann, & Brock, 2005). This may be because salient and distinctive cues attract more attention and elicit more extensive processing (Einstein et al., 2000).

The literature on external reminder cues indicates that placing a reminder cue following signalized traffic intersections within school zones may prompt prospective memory retrieval. Thus, a second goal of our article is to examine whether introducing a flashing "check speed" reminder sign can mitigate any disruptive effect of intersection interruptions on motorists' speed. Additionally, the introduction of the reminder sign will allow us to examine whether increased driver speed is more likely due to prospective memory retrieval error or to a competing theory: the frustration hypothesis.

Frustration involves the "blocking or thwarting of some form of ongoing, goal-directed behavior" (Ozkan, Lajunen, Parker, Sumer, & Heikki, 2010, p. 228). Research examining the role of frustration within the road traffic domain has found that frustrating traffic conditions such as delays and congestion have been associated with drivers exhibiting a greater propensity to weave across lanes, honk horns, drive through red lights (Shinar & Compton, 2004), apply more pressure to the accelerator pedal, and speed more frequently (Stephens & Groeger, 2009). The traffic light speed impediment within school zones may therefore be a frustrating driving condition that increases the risk of increased speed upon driving resumption. In an attempt to reconcile which theoretical position may better account for speeding errors, we propose that if the inclusion of a flashing reminder cue should prompt motorists to recall that they are still traveling in a school zone, and they accordingly resume their journey at the appropriate speed, then such a finding would provide support for the prospective memory account. However, if the reminder cue should have no salutary effect on the speed of the resumed journey then this outcome would be more consistent with a frustration account of the speeding errors, in that drivers continued to accelerate to speeds beyond the school zone limit out of the frustration of being interrupted.

The Current Studies

In Study 1 we examined whether being interrupted by signalized traffic intersections within school zones can influence motorists' speed upon driving resumption. To do so we compared the speeds of motorists who were interrupted and required to stop at signalized intersections within school zones to those of motorists who had an unimpeded passage through them. As control conditions, data were also collected from motorists who traveled within school zone hours but outside of school zone days of operation (i.e., during school holidays) to provide an indication of what speeds drivers achieve when they do not have to be mindful of the reduced school zone speed limit. We predicted an Interruption by School-Time interaction. We expected interrupted motorists would record faster vehicle speeds when measured 100 m from the traffic intersections than noninterrupted motorists during school time, but this would not be the case for motorists outside of school time.

In Study 2 we assessed whether introducing a flashing "check speed" reminder sign, positioned 70 m after the traffic light intersections, could mitigate any interruptive effect found in Study 1. Here, we predicted an Interruption by Warning-Light interaction. We expected no difference in speed for interrupted versus noninterrupted motorists when warning cues were provided.

Study 1

A sample of motorized vehicles was observed traveling through signalized road intersections in four designated school zone areas across metropolitan Sydney, New South Wales, Australia. In total, the vehicle speeds from 4,946 motorists was recorded. Of these motorists, 2,496 were noninterrupted motorists during school time, 647 were interrupted motorists during school time, 1,345 were noninterrupted motorists outside school time, and 458 were interrupted motorists outside school time.

Selection Criterion for Noninterrupted Conditions

A criterion value of 3 s was used to differentiate whether individual vehicles were to be included in noninterrupted conditions. If a target vehicle had a following distance of less than 3 s, then the vehicle was considered to be in a platoon (i.e., where the following distance between vehicles is minimal and drivers do not have full discretion over their speed) and the observed speed was not recorded. If a target vehicle had a following distance greater than 3 s, then the vehicle was used for speed analysis. This criterion value was selected based on observable driver behavior and its use in previous observational driver studies (see Simons-Morton, Lerner, & Singer, 2005). Two observers were used to make these judgments and inclusion as an instance of observed speed required agreement between both observers. Observers completed the recording of all data from one vehicle before observing the next available vehicle they saw when looking backup from the data collection form (as recommended by Eby, 2011).

Selection Criterion for Interrupted Conditions

Only the first row of stationary vehicles waiting at the intersections were considered for analysis as interrupted vehicles. This

controls for any possible rolling out, where vehicles roll for a certain amount of time or distance before speed measurement begins and controls for the possibility of vehicle speeds ahead dictating accelerating pace.

Locations

The selection of school zone intersections was based on four criteria. First, it was necessary that each location provided the ability to conceal the observers' behavior from passing motorists. Second, it was important that there was a minimum 110 m distance between the traffic light and the "end of school zone" sign. This enabled observers to stand 100 m from the traffic light intersections and for interrupted motorists to reach speeds in excess of 40 km/h (i.e., the school zone speed limit in New South Wales) under normal (i.e., unrestricted) driving conditions. Third, the road had to be noncongested so that motorists dictated their own speed. Fourth, because school zone flashing signs are better able to capture motorists' attention than static signs, and consequently are more effective at reducing speed (Roper et al., 2006), only school zones that were demarcated with the flashing 40 km/h signs at the entry into the zone were selected. Drivers were therefore observed under the assumption that they had identified the need to comply with school zone regulations.

Based on these selection criteria, a total of four intersections within school zones were selected across the metropolitan area in Sydney, Australia. All intersections were located on arterial roads. Traffic lights at all locations turned red once every 2 min. Variations between locations included the following: two of the locations had a speed limit of 60 km/h prior to entering the school zone, one had a speed limit of 70 km/h prior to entering the school zone, and one had a speed limit of 80 km/h prior to entering the school zone. Locations also differed between the width of the lanes and also the number of lanes (three of the locations had three lanes, one had two lanes). No systematic differences were found in terms of vehicular speed recordings between the different groups of speed limits, locations, and lane numbers. As a consequence, these variables were not included in any analyses. Degree of traffic congestion also differed across locations; however all met the 3-s between car inclusion criteria. It was anticipated that these variations would increase the generalizability of present findings.

Apparatus

A Bushnell's Velocity Speed Gun (Model 101911) was used to measure vehicle speed. It has an accuracy of +/− 1.6 km/h and can measure the speed of vehicles traveling between 16 and 322 km/h up to 475 m away. The gun uses digital signal processing to capture the maximum speed of the vehicle of interest. Once the trigger of the speed gun is released, the maximum speed of the target vehicle is captured and is visible on the liquid crystal display until speed measurement is reinitiated by pressing and holding the trigger (Bushnell, 2010).

Procedure

Data collection occurred between the months of February 2012 and April 2012, Monday to Friday during school zone times (8:00 a.m. till 9:30 a.m. and 2:30 p.m. till 4:00 p.m.) and when weather conditions permitted dry roads. At each site location, observers would stand 100 m from the traffic light intersection behind a tree or in a bus shelter while collecting data. To a passing motorist, it was intended that the observers would appear to be two people having a conversation at the roadside. Observer 1 looked in the direction of approaching traffic and would place a scarf over the speed gun to conceal it from passing motorists while taking vehicle speeds. These two steps were taken to conceal the observers' behavior from passing motorists. Observer 2 faced Observer 1 and looked away from the approaching traffic, recording the speeds of the vehicles read out by observer one on the data collection form. This procedure was identical for all participant conditions across Study 1 and Study 2.

Results

Due to the amount of power available (over 99% for all tests), significance was set at .001 to ensure only scientifically important effects were detected. A full factorial Interruption (interrupted, noninterrupted) × School Time (within school time, outside school time) between subjects analysis of variance was conducted on vehicle speed. A significant main effect of School Time, $F(1, 7002) = 1693.90$, $p < .001$, but no main effect for Interruption, $F(1, 7002) = 2.76$, $p = .097$), was found. There was a significant interaction between Interruption and School Time, $F(1, 4934) = 745.02$, $p < .001$ ($r = .55$; see Figure 1), indicating that vehicular speed differences between interrupted and noninterrupted motorists differed depending on whether they were in school time or outside school time.

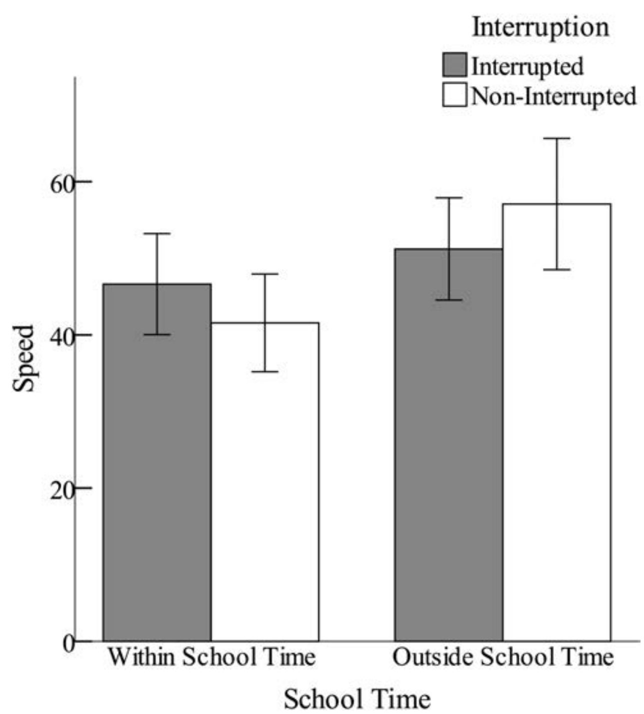

Figure 1. Comparison of mean vehicular speeds (in km/h) for motorists traveling within school time and outside of school time across motorists who were interrupted and noninterrupted for Study 1. Error bars represent one standard deviation.

Simple effects analyses were conducted to examine the speed differences between interrupted and noninterrupted motorists who were traveling either inside or outside of School Time. As hypothesized, during school time interrupted motorists ($M = 48.27$, $SD = 6.32$) recorded significantly faster vehicular speeds than noninterrupted motorists ($M = 41.76$, $SD = 5.93$), $t(3141) = 11.35$, $p < .001$, 95% CI [5.98, 7.02], $d = 1.08$, 95% CI [0.87, 1.29]. This finding suggests that stopping at signalized traffic intersections within school zones can increase the speeds of motorists when measured 100m from these intersections. Outside of school zone time, however, noninterrupted motorists ($M = 57.98$, $SD = 7.53$) recorded faster vehicular speeds than interrupted motorists ($M = 51.45$, $SD = 6.49$), $t(1801) = 14.99$, $p < .001$, 95% CI [5.68, 7.39], $d = 0.90$, 95% CI [0.56, 1.23]. This was not an expected finding, and may suggest that in general, drivers feel comfortable accelerating to these approximate speeds after being required to stop at a signalized traffic intersection.

Study 2

Study 2 was designed to examine whether the vehicle speeds of interrupted motorists within school zones can be reduced overall by the introduction of a flashing "check speed" sign stationed 70 m from traffic light intersections. Study 2 was also designed to examine which theoretical position may better account for speeding errors: the prospective memory hypothesis or the frustration hypothesis. According to the prospective memory hypothesis, motorists exhibit prospective memory errors after being interrupted by signalized traffic intersections, and this may be overcome by the presence of a warning cue. Alternatively, the frustration hypothesis suggests that motorists are frustrated at being interrupted by the signalized traffic intersection, and will therefore exhibit faster speeds regardless of the presence of a warning cue. Inclusion of the flashing "check speed" reminder sign was all that differed between Study 1 and Study 2.

In total, the vehicle speeds from 1,846 motorists was recorded. Of these motorists 256 were noninterrupted motorists that had no warning cue, 64 were interrupted motorists that had no warning cue, 2,496 were noninterrupted motorists with a warning cue, and 647 were interrupted motorists with a warning cue.

Apparatus

A flashing "check speed" sign was used. The sign was 850 mm in length, 380 mm in width and had two 100 mm diameter flashing lights that were separated by the writing "check speed." The lights connected to a 12 V battery, and were internally programmed to activate during school zone times and days. When activated, the lights flashed in an alternating fashion at oncoming motorists. The sign was attached to a ladder (2.5 m high) by two clear cable ties. The whole apparatus was positioned 70 m from the traffic light intersections (visible to motorists waiting at the traffic light to facilitate the encoding process) on private property at the four locations.

Results

Manipulation check for the flashing lights. In order to ascertain whether it was the flashing lights of the check speed sign that led to the difference in vehicle speeds between conditions, and not the additional characteristics of the apparatus that was novel to this experiment (i.e., the ladder, weights, and battery), a manipulation check was conducted. This involved assembling the flashing "check speed" sign identically to when it was used in the primary analyses; however, the sign was not connected to the battery and therefore the lights did not flash.

T tests were conducted in order to compare the vehicle speeds of motorists who had no warning cue at all (i.e., no warning noninterrupted and no warning interrupted conditions; Study 1 data where there was no ladder present) and those who had the warning cue but it was turned off (i.e., warning-off-non interrupted and warning-off interrupted conditions; Study 2 data with the ladder set-up as described above). Results of two independent *t* tests revealed that there was no significant difference in vehicle speeds between the no warning noninterrupted ($M = 41.76$, $SD = 5.93$) and warning-off noninterrupted conditions ($M = 40.95$, $SD = 6.35$), $t(302) = 1.95$, $p = .052$, 95% CI [−0.04, 1.58], $d = 0.13$, 95% CI [−0.09, 0.36]; and no significant difference in vehicle speeds found between the no warning interrupted ($M = 48.27$, $SD = 6.32$) and warning-off interrupted conditions ($M = 47.67$, $SD = 7.63$), $t(709) = 0.70$, $p = .482$, 95% CI [−1.05, 2.25], $d = 0.12$, 95% CI [−0.38, 0.57]. These findings indicate that when the "check speed" sign was assembled but the lights were turned off, motorists resumed speeding as if there was no apparatus present (i.e., equivalent to Study 1 data). Therefore, any reduction in speed in the following analyses can be attributed to the existence of the flashing lights and not to the novel structure of the sign equipment. These Study 2 warning-off interrupted and warning-off noninterrupted conditions were used for the following primary analyses.

Do interrupted motorists reduce speed with a reminder? Due to the amount of power available (over 99% for all tests), significance was set at .001 to ensure only scientifically important effects were detected. A full factorial Interruption (interrupted, noninterrupted) × Warning (warning, no warning) between subjects analysis of variance was conducted on vehicle speed. The significant main effect of Interruption, $F(1, 1842) = 107.10$, $p < .001$, and the significant main effect of Warning, $F(1, 1842) = 152.47$, $p < .001$, were qualified by a significant interaction between Interruption and Warning, $F(1, 1842) = 40.41$, $p < .001$ ($r = .10$; see Figure 2). This interaction signifies that vehicular speed differences between interrupted and noninterrupted motorists differed depending on whether there was a warning cue present or not.

Simple effects analyses were conducted to examine the speed differences between interrupted and noninterrupted motorists who encountered or did not encounter a warning. For those with no warning, interrupted motorists ($M = 47.76$, $SD = 7.63$) recorded significantly faster vehicle speeds than noninterrupted motorists ($M = 40.95$, $SD = 6.35$), $t(318) = 7.26$, $p < .001$, 95% CI [4.90, 8.54], $d = 1.05$, 95% CI [0.58, 1.53], indicating that motorists who are required to stop at signalized traffic intersections without the presence of a warning cue show faster vehicle speeds than those who have an unimpeded passage through them. This finding is a direct replication of Study 1. For those with a warning cue, interrupted motorists ($M = 40.15$, $SD = 5.33$) also recorded significantly faster vehicular speeds than noninterrupted motorists ($M = 38.54$, $SD = 4.92$), $t(1524) = 5.79$, $p < .001$, 95% CI [1.06, 2.15], $d = 0.32$, 95% CI [0.15, 0.50]. However, the increase in

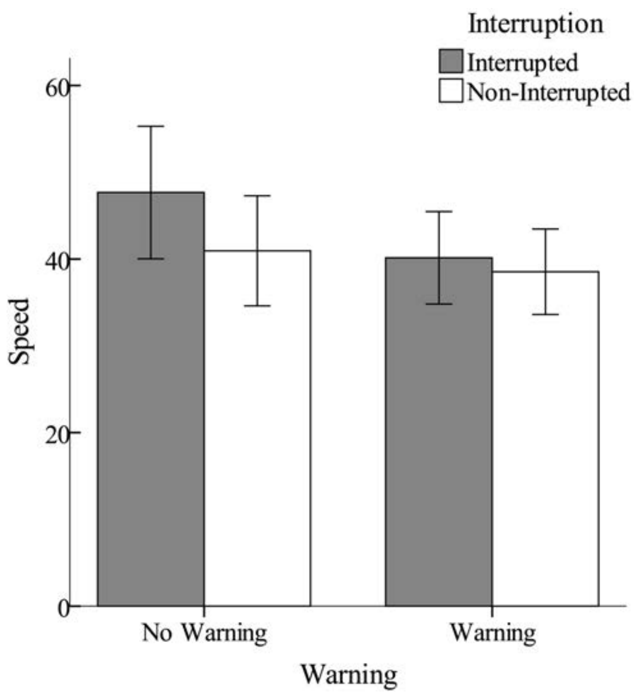

Figure 2. Comparison of mean vehicular speeds (in km/h) for interrupted and noninterrupted motorists across the presence of a warning cue or no warning cue for Study 2. Error bars represent one standard deviation.

speed for interrupted versus noninterrupted motorists is larger under no warning conditions than under warning conditions.

Simple effects analyses were also conducted to examine the speed differences between warning cue and no warning cue for motorists who encountered or did not encounter an interruption. Motorists in the warning-off interrupted condition (M = 47.76, SD = 7.63) recorded significantly faster vehicle speeds than motorists in the warning interrupted condition (M = 40.15, SD = 5.33), $t(1134) = 22.92$, $p < .001$, 95% CI [7.42, 8.81], d = 1.37, 95% CI [0.96, 1.78]. Thus, the provision of the warning cue reduced the effect of interruption on driving speed. Motorists in the warning-off noninterrupted condition (M = 40.95, SD = 6.35) also recorded significantly faster vehicular speeds than motorists in the warning noninterrupted condition (M = 38.54, SD = 4.92), t(1524, $t(2312) = 15.40$, $p < .001$, 95% CI [2.84, 3.60], d = 0.57, 95% CI [0.29, 0.66], indicating that in addition to reducing interruption speeds, the provision of the warning cue also reduced the speeds of motorists who were not required to stop at the signalized traffic intersections.

General Discussion

Overall, the aim of the two studies reported in the present article was to examine whether the presence of signalized traffic intersections in the middle of school zones can influence vehicular speeds upon driving resumption, and whether introducing a reminder cue after the intersection can offset any interruption effect. The empirical findings can be summarized as follows. During school time, motorists who were interrupted by signalized intersections recorded faster vehicle speeds than noninterrupted motorists (Study 1). In Study 2, the provision of the warning cue reduced the effect of interruption on driving speed. It also reduced the speeds of motorists who were not required to stop at the signalized traffic intersections.

Examining the means, during school time interrupted motorists sped, on average, 8.27 km/h over the 40 km/h speed limit when measured 100 m from traffic intersections whereas noninterrupted motorists sped, on average, 1.76 km/h over the speed limit (Study 1). With regard to the introduction of a reminder cue, speed reductions of 6.81 km/h and 1.61 km/h were reported for interrupted and noninterrupted motorists respectively (Study 2). These speed reductions suggest that having signalized traffic intersections in school zones may result in prospective memory errors.

Theoretical and Practical Implications

These results are consistent with previous research examining the influence of interruptions on task performance (Altmann & Trafton, 2002; Dismukes, 2012; Dodhia & Dismukes, 2009; Trafton, Altmann, Brock, & Mintz, 2003), which argues that task interruptions can facilitate prospective memory errors. Specifically, the findings suggest that (a) signalized traffic intersections in the middle of school zones may interrupt the primary task of driving at the school zone speed limit, and that (b) the introduction of a reminder cue may counteract prospective memory loss by reminding drivers of their original task of traveling at or below the school zone speed limit. This study therefore adds to the literature (Altmann & Trafton, 2002; Dismukes, 2012; McDaniel et al., 2004) by providing a practical, everyday example in which interruptions can negatively impact task performance (Monk, Boehm-Davis, & Trafton, 2004) and how reinstating a reminder cue can facilitate task resumption (Altmann & Trafton, 2002; McDaniel & Einstein, 2000; Trafton, Altmann, & Brock, 2005).

The findings are also consistent with the literature examining visual search and attention. In particular, it supports the assertion that bottom-up pathways are exogenously driven by the external environment and are highly efficient at capturing visual attention (Shomstein, 2012). Here, the flashing "check speed" sign can be thought of as an exogenous stimulus that has captured the visual attention of passing motorists. Present findings also underscore the importance of recognizing and adopting a systems approach to human error (Reason, 2000). The systems approach to human error suggests that, applied to a road traffic context, latent factors in the road environment can influence whether drivers speed or not (Ellison, Greaves, & Daniels, 2011). Current thought is that speeding is an intentional behavior (the person centered approach) and thus speed management initiatives should rely on deterrence methods in order to reduce speed. For example, Ebrahim and Nikraz (2012) suggest that to combat speeding behaviors around school zones, speed enforcement methods should be emphasized, such as enhancing more roadside camera hours around school zones. However, present findings propose that speeding within school zones can be an inadvertent error influenced by signalized intersection interruptions, and that the road environment has a role to play in speeding behavior.

Perhaps the most important practical implication concerns how road infrastructure around school zones may be modified to improve the safety of children, and pedestrians and cyclists, during the journey to and from school. The need for drivers to comply

with speed limits around school zones is particularly important given the increased travel activity by children within these areas, and the increased risk and consequences of a collision (Ellison et al., 2011). Children are especially vulnerable around school locations not only because of their increased exposure (Staysafe Committee, 2001; Staysafe Committee, 2012; Warsh, Rothman, Slater, Steverango, & Howard, 2009) but also because of their unpredictability and size compared with other road users (Roads & Traffic Authority, 2012; Staysafe Committee, 1994).

Research has shown that relatively small increases in vehicular speeds can lead to both an increased chance of a collision and an increased chance of a fatality in the occurrence of a collision (Mountain, Hirst, & Maher, 2005; Roads & Traffic Authority, 2012). According to Peden et al. (2004), the risk of fatality in a pedestrian collision doubles if a vehicle is traveling at 50 km/h compared with one that is traveling at 40 km/h. The 8.27 km/h increase in speed above the 40 km/h school zone speed limit exhibited by motorists who were interrupted by signalized traffic intersections in the present study, as well as the 6.81 km/h reduction after the introduction of a reminder cue, can therefore be considered vital differences, representing a halving of the fatality risk should a pedestrian collision occur by such an intervention. Thus, governments and road designers should use the information presented in this article to be more aware, and be more equipped to deal with, the road environmental factors that impact on driver behavior. The introduction of a flashing "check speed" reminder sign positioned 70 m after the traffic light intersections has been implicated here to be a potential solution to such a problem where intersection infrastructure in the middle of school zones already exists. Currently within school zones in Australia, there are no flashing reminder signs following signalized traffic intersections.

Limitations and Future Directions

It is important to note several limitations of the present studies. Information regarding the make of the vehicle (to control for differences in acceleration speeds) or whether vehicles had built-in GPS devices to monitor speed was not collected. We believe, however, that these factors would not have impacted greatly upon our results. In fact, if vehicles were included in the overall sample that had slow acceleration speeds or were equipped with GPS devices then present results are more likely to be conservative than what they could be in another sample.

Concerns about the potential problem of unequal sample sizes in different conditions and lack of independence of observations can also be raised. In order to minimize our findings being a result of chance violations of assumptions, however, cases were randomly deleted in order to achieve a balanced design. These analyses revealed no difference in patterns of significance. Similarly, although we acknowledge that traffic flow might result in observations being nonindependent, this argument would be more valid if every single vehicle within the stream of traffic was recorded. This was not the case. Recordings were done on a random basis to minimize any systematic attempt in measurement.

To completely rule out the role of frustration impacting upon the results in Study 1 would also be premature. Indeed, it could be that both feelings of frustration and prospective memory lapses are occurring at the same time and contributing to increased interruption speeds. For instance, drivers may feel frustrated after being interrupted by traffic intersections, momentarily forget that they are within a school zone, and accelerate to speeds beyond the 40 km/h speed limit. The speed reductions found in Study 2 may indicate that frustrated drivers remain responsive to speed reminders.[1]

Additionally, alternative explanations for the data may be considered: It may be that there are certain speeds that drivers feel more comfortable accelerating to after a stop. For example, accelerating to speeds of approximately 50 km/h may be more comfortable than accelerating to speeds of 40 km/h within a school zone. This explanation may be supported by the unexpected finding that interrupted motorists outside school time recorded average speeds of 51 km/h, compared with the average speeds of 58 km/h for noninterrupted motorists outside school time (Study 1). Here, both conditions were not required to travel at the 40 km/h school zone speed limit and therefore by all accounts average speeds should have been similar. Moreover, the average speeds of interrupted motorists during school time and interrupted motorists outside school time were nearly identical, perhaps supporting a comfortable acceleration speed hypothesis. Again, it is also possible that both ease of acceleration and lapses in prospective memory are co-occurring: Drivers may naturally accelerate to a certain speed and forget that they should be driving slower (during school zone speed limit) or that they could go faster (when no school zone speed limit applies).[1] Alternatively, these results may be a product of methodological design. After being interrupted by signalized traffic intersections, vehicles may only have the potential to accelerate to 50 km/h when measured 100 m from the traffic light intersections. If this were the case, it could be argued that the effects observed for motorists in the accelerate condition may actually be an *underestimation* of how fast motorists would be willing to go when school times are operating.

Despite these limitations, this is the first study to identify the need to quantify and describe the influence of signalized traffic intersections on speeding behavior. As a result, future studies may find this study to be a good starting point from which to derive testable hypotheses about the role of prospective memory and intersection interruptions, perhaps through the use of a driving simulator. Future research may also wish to explore the effectiveness of the flashing "check speed" sign in reducing vehicular speeds over time. Research examining the effectiveness of stimuli in determining levels or patterns of responsiveness has suggested that novel or unfamiliar stimuli may increase behavioral responding, at least initially (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990). Thus, the novelty of the flashing "check speed" sign in the present study may have contributed to the speed reductions found in Study 2. An examination into whether these effects habituate and reduce over time is warranted.

Research also suggests that different stimuli on road signs may tap into two different mechanisms in order to facilitate behavior: early perceptual processing through repetition priming, and semantic processing influencing cognitive processes (Gehlert, Schulze, & Schlag, 2012). These mechanisms may have different effects on prompting behavior. For example, Koyuncu and Amado (2008) found that signs which only tap into repetition priming (e.g.,

[1] We thank the helpful comments of an anonymous reviewer for these suggestions.

symbol signs) produce slower reaction times (RTs) compared with signs which only tap into semantic processes (e.g., written "check speed" signs) and signs that combine the two processes. The present study used a sign that included both repetition priming (i.e., the flashing symbol) and semantic processing (i.e., the "check speed" writing). One avenue for future research may therefore be to cover the "check speed" part of the warning sign in one condition, and the flashing lights in a different condition, and examine whether these manipulations lead to different outcomes in driver speed. Finally, extension of these results to examine other driving situations where motorists may be interrupted by various tasks or road design infrastructures (e.g., roundabouts and pedestrian crossings) is also suggested.

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