2020

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Original Publication Citation

Samuel, S., Yahoodik, S., Yamani, Y., Valluru, K., & Fisher, D. (2020). Ethical decision making behind the wheel – A driving simulator study. *Transportation Research Interdisciplinary Perspectives, 5*, 1-7, Article 100147. https://doi.org/10.1016/j.trip.2020.100147

Transportation Research Interdisciplinary Perspectives 5 (2020) 100147

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: https://www.journals.elsevier.com/transportation-research-interdisciplinary-perspectives

Ethical decision making behind the wheel – A driving simulator study

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ARTICLE INFO

Article history:
Received 19 February 2020
Received in revised form 23 May 2020
Accepted 1 June 2020
Available online 11 June 2020

Keywords:
Moral judgment
Driver-less policy
Eye movements
Utilitarianism
Ethical decision making
Driver behavior

ABSTRACT

Over the past several years, there has been considerable debate surrounding ethical decision making in situations resulting in inevitable casualties. Given enough time and all other things being equal, studies show that drivers will typically decide to strike the fewest number of pedestrians in scenarios where there is a choice between striking several versus one or no pedestrians. However, it is unclear whether drivers behave similarly under situations of time pressure. In our experiment in a driving simulator, 32 drivers were given up to 2 s to decide which group of pedestrians to avoid among groups of larger (5) or smaller (≤ 1) number of pedestrians. Our findings suggest that while people frequently choose utilitarian decisions in the typical, abstract manifestations of the Trolley Problems, drivers can fail to make utilitarian decisions in simulated driving environments under a restricted period of time representative of the time they would have to make the same decision in the real world (2 s). Analysis of eye movement data shows that drivers are less likely to glance at left and right sides of crosswalks under situations of time duress. Our results raise critical engineering and ethical questions. From a cognitive engineering standpoint, we need to know how long at minimum a driver needs to make simple, moral decisions in different scenarios. From an ethical standpoint, we may need to evaluate whether automated vehicle algorithms can aid decision making on our behalf when there is not enough time for a driver to make a moral decision.

1. Introduction

Ethical decision-making problems have been widely studied in different domains such as healthcare, economics and driving (Awad et al., 2018; Frison et al., 2016; Kälvemark et al., 2004; Dickinson and Masclet, 2019). In driving, humans are destined to face infrequent yet safety-critical situations where casualties are inevitable (Goodall, 2014). These scenarios could require us to make ethical decisions in a limited amount of time. For example, with insufficient time to brake, drivers may have to choose to save five pedestrians crossing the road by veering to the side and instead striking only one pedestrian, a response that might be infeasible for the driver as the available time to action (swerve left or right) reduces. The primary question then surrounds the minimum time required by a driver to make a moral decision in a safety-critical scenario.

The Trolley Problem is a popular paradigm for studying moral decision-making processes (Foot, 1967; Thomson, 1976). In the switch Trolley Problem, the most common manifestation of the Trolley Problem, participants are asked to decide whether to flip a switch to change the path of a trolley that is heading towards five people to a separate track where one person is standing. Typically, when faced with this moral dilemma, the majority of people behave in a utilitarian manner by choosing to sacrifice one individual to save a group of people. Survey studies consistently show that humans prefer making utilitarian decisions in Trolley Problem scenarios (Bleske-Rechek et al., 2010). Recently, the Trolley Problem was studied in a dynamic, virtual-reality environment (Navarrete et al., 2012). Navarrete et al. (2012) reported that 89% of participants across conditions chose the utilitarian outcome which was to pull the switch and kill one individual rather than do nothing and kill five individuals. Several studies demonstrate that participants' subjective and psychological responses in virtual reality environments closely map their experience and behaviors in real world settings (Slater et al., 2006).

While utilitarianism is a popular model for how humans make decisions in safety-critical scenarios (Bonnefon et al., 2016), until recently the empirical evidence that most humans are utilitarian was largely limited to the realm of thought experiments. It remained unclear whether humans would consistently choose the utilitarian decision if actually placed in a situation which required them to take an action consistent with what they said they would do. Recent

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http://dx.doi.org/10.1016/j.trip.2020.100147

studies have provided a partial answer to this question. For example, in one study, a virtual environment was used to assess whether participants would choose to hit one pedestrian in the road over multiple pedestrians (Faulhaber et al., 2019). Overwhelmingly, participants opted to make a utilitarian decision. A similar study, examining the effects of time pressure and naturalism of the method (VR or text based) used to assess moral decision making, found that time pressure, but not necessarily realism, led to fewer decisions favoring saving the lives of young avatars and female avatars, contrary to what was seen without time constraints (Sütfeld et al., 2019). Yet, another study examining the interplay between intuitive and cognitive processes related to moral judgments found context-dependent gaze durations during decisions that involved sacrifice, leading participants to look for prolonged durations at their victim, particularly if they had to choose between avatars from differing genders (Skulmowski et al., 2014).

The second of the above three experiments suggests that as the time available to make a decision decreases, the individual diverges from what his or her decision might be when there is more than enough time to make the decision (Sütfeld et al., 2019). In this regard, it is worth noting that in the first of the above three experiments where the participants had 4 s to respond, making a choice in that period of time is consistent with the choice they would make without time constraints. Thus, one could confidently hand decision-making responsibilities over to the driver in such situations. But, critically, there will come a point when the driver will not have enough time to react, let alone decide. From a cognitive engineering standpoint, we need to know when the time is too short for a driver to make a decision consistent with the decision he or she would make over a longer period of time.

With this in mind, a study was undertaken of the decisions that drivers would make in a scenario which mimics the Trolley Problem under time constraints which are more typical of those that might occur in real traffic. We chose 2 s as the time delimited period because it is typical of the length of time drivers have to make a life or death decision going at freeway speeds in heavy traffic (Mordipour, 2014). Additionally, we chose to introduce eye movement data to moral cognition research due to its finer temporal resolution. Please note that gaze behavior in relation to sacrificing decisions in a trolley dilemma context has already been investigated in pen and paper studies that show people typically avoid looking at pictures of the sacrificed individuals (Kastner, 2010). While gaze behavior has been explored in one previous VR study (Skulmowski et al., 2014), the said study focused on the temporal duration of the gaze while our study focuses on the salient accuracy of the fixation.

Specifically, the current driving simulator study examined whether drivers make utilitarian decisions in situations of unavoidable harm as frequently as previously reported when in control of the vehicle and forced to make a choice in an interval of just 2 s between striking five pedestrians versus one pedestrian (Scenario 1) or no pedestrians (Scenario 2).

2. Methods

2.1. Participants & design

Thirty-two paid participants (14 females; mean age = 29.2 years, SD = 12.6 years; mean years since licensure = 10.5 years, SD = 11.2 years) were recruited from the University of Massachusetts Amherst and surrounding areas. Sixteen participants were assigned to Scenario 1 and sixteen participants were assigned to Scenario 2. Following a between-subject design, drivers were randomly allocated to one of two scenarios. All participants reported good health, had normal or corrected-to-normal visual acuity, and held a valid US driver's license. Participants were of varying education levels and included university students, local town workers, university staff and rural entrepreneurs.

2.2. Apparatus

2.2.1. Driving simulator

A high-fidelity driving simulator (Real-Time Technologies Inc., Ann Arbor, MI) consisting of a full-body 2013 model Ford Fusion Sedan, five forward facing projection screens and a single rear-end projection screen, and a surround speaker system was used in this study. The virtual environment was projected to the forward screens with a resolution of 1920 × 1200 pixels and to the rear screen with a resolution of 1400 × 1050 pixels with display refresh rate of 60 Hz. The simulator provided approximately 330° of a field of view.

2.2.2. Eye tracker

A Mobile Eye XG eye tracker (Applied Science Laboratory, Cambridge, MA) was used to track and record participants' eye movements. The eye tracker sampled the position of the eye at 30 Hz with a visual range of 50° horizontally and 40° vertically and simultaneously recorded an image of the forward roadway at 30 Hz. The superimposed eye and forward roadway scene data were analyzed using the ASL Eye Map software.

2.3. Driving scenarios

Two separate scenarios were designed for the two experiments. The 0.85-mile long scenarios consisted of two lanes in each direction and involved ambient traffic, buildings, some vegetation, and fog. A crosswalk was placed 3520 ft from the beginning of each scenario. For both Scenario 1 and 2, there was a horizontal curve obscuring the upcoming crosswalk. The intensity of fog was controlled so that the participants could see the pedestrians only 2 s before the crash. The speed limit was 45 mph as is typical of curved roadsections in Massachusetts. Further, to provide experimental control, all participants were asked to stay on the rightmost lane (of two lanes). Participants closely adhered to the speed limit and requested lane placement. Approximately 16 s prior to the cross-walk scenario, a series of 5 black screen interruptions were presented for 2 s each with a 1-second time interval between the black screens. The last black screen was presented 2 s prior to the point where the drivers can first view the pedestrians. The sensors were location-based so that the interruptions occurred at the same location on the roadway for all participants across both scenarios. The alternating black screens and forward views of the roadway mimicked the information a driver would receive who was alternately glancing between an in-vehicle task and the forward roadway (Samuel and Fisher, 2015).

2.3.1. Scenario 1

In this scenario, there was one pedestrian entering the crosswalk from the left side and five pedestrians from the right side, equally distant from the driver (Fig. 1). The pedestrians were timed, and the scenario was programmed such that loss of either one or five pedestrians was unavoidable. More specifically, the scenario is designed to be a 2-alternative forced-

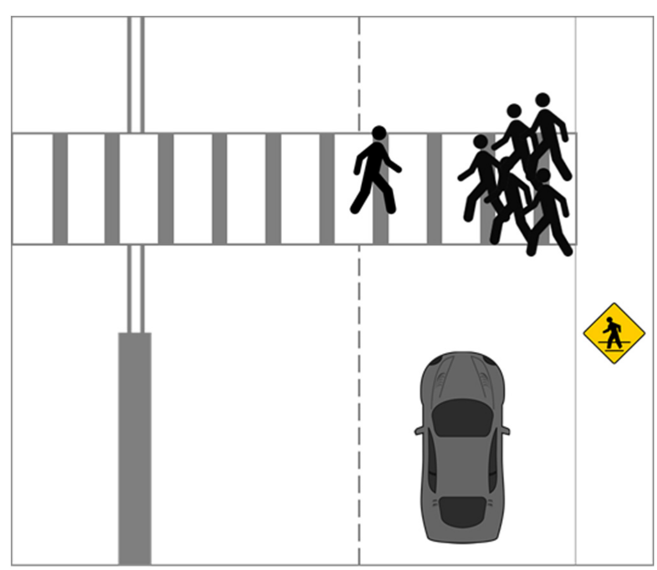

Fig. 1. Driving scenario 1.

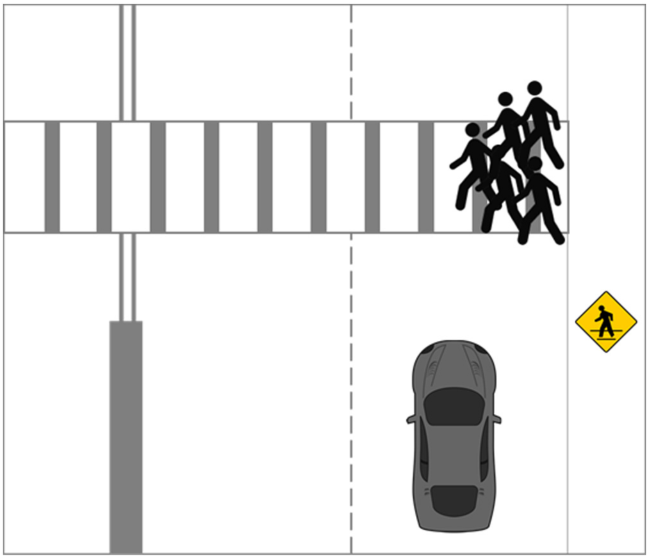

Fig. 2. Driving Scenario 2.

choice task. By a combination of design (scripting) and mechanics (brake coefficient), we have effectively constructed a scenario where drivers need to make one of two decisions that both involve some form of swerving (either left or right). Braking was not an effective option because the posted speed limit was high enough that any braking action would result in a collision given the small braking distance and resultantly small (in the order of milliseconds) time to collision window.

In the first scenario, the participant is driving in the right lane, on a four-lane road. After being obscured by fog, a group of five pedestrians appeared in front of the car in a crosswalk two seconds before the driver would strike the group unless an evasive action was taken. One pedestrian was approaching from the left. Fig. 3 presents perspective views of both scenarios.

2.3.2. Scenario 2

In the second scenario (see Fig. 2), the participant is driving in the right lane, on a four-lane road. After being obscured by fog, a group of five pedestrians appeared in front of the car in a crosswalk. There were no pedestrians to the left. All other elements were the same as Scenario 1.

2.4. Procedure

Participants provided explicit written consent to participate in this study. The experimenter provided a set of general instructions for driving in virtual environments and a couple of practice drives to familiarize the participants with the driving simulator. After the practice drives, the participants were outfitted with an eye tracker which was then calibrated using a 9-point scene calibration process. Following this, the participant completed one of the two driving scenarios that they were randomly assigned to. Their task was to drive each scenario at the speed limit (45 mph), following regular traffic rules in the Commonwealth of Massachusetts while staying in the right lane. Following the experimental drives, they were asked to complete a post-study questionnaire that included basic demographic information, driving history, and subjective ethics questions (the complete list of subjective ethics questions are included in an appendix following references). There was a total of 16 items on the post-study questionnaire that were subjective measures of ethics. These items were assessed on a five-point Likert rating scale with a rating of 1 implying strong disagreement and a rating of 5 noting strong agreement. No other instructions were given to participants.

2.5. Data analysis

Eye movements of the drivers were manually coded by two independent raters to judge whether each driver glanced at the right or left extremities of the crosswalk in each 2-second interval between the black screens. If the two raters disagreed, they discussed such glances and resolved the disagreement. The variable was binary coded such that the presence of right or left glances is coded as "1" or the absence as "0". Previous experiments analyzing gaze duration towards sacrificed and non-sacrificed avatars used the entire left and right half of the screen as areas of interest (Skulmowski et al., 2014). For ethics questionnaire items, each driver gave their rating on the 5-point Likert scale (1: Strongly Disagree – 5: Strongly Agree).

3. Results & discussion

To analyze the data, we conducted one-sample *t*-tests comparing the obtained data against the reported proportion in Navarrete et al. (2012). In Scenario 1, only 43% of the participants chose the utilitarian outcome [with a 95% confidence interval (CI) of 20–69]. This proportion is significantly less than the 89%, reported by Navarrete et al. (2012) in which the drivers had 4 s to make a decision ($p < .001$). The participants glanced towards the left and right extremities of the crosswalk less frequently when comparing the two-second safety-critical interval to the control intervals prior to the critical interval. Eye movement data were entered to a series of one-way repeated-measures analyses of variance (ANOVAs) with Interval as a within-subject factor, separately for glances to the left and the right extremities.

Figs. 4 and 5 show mean number of proportions glancing to the right and left extremities in Scenario 1 and 2 respectively, with the safety-critical interval highlighted. In Scenario 1, more drivers glanced to the right during the 1st interval then progressively less until the end of the scenario [$F(4, 60) = 3.46, p = .01$] but similar number of drivers glanced to the left extremity during the simulated drive [$F(4, 60) = 1.13, p = .34$],

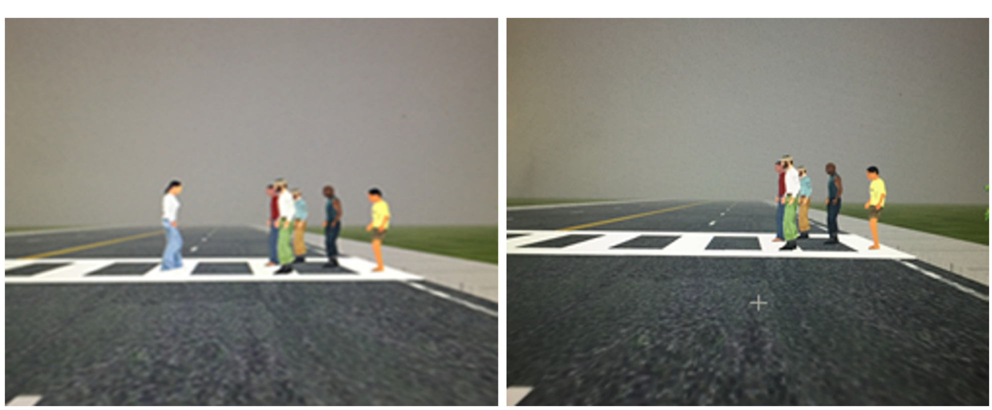

Fig. 3. Left Panel: Scenario design with one pedestrian on the left and 5 pedestrians on the right; Right Panel: Scenario design with no pedestrian on the left and 5 pedestrians on the right.

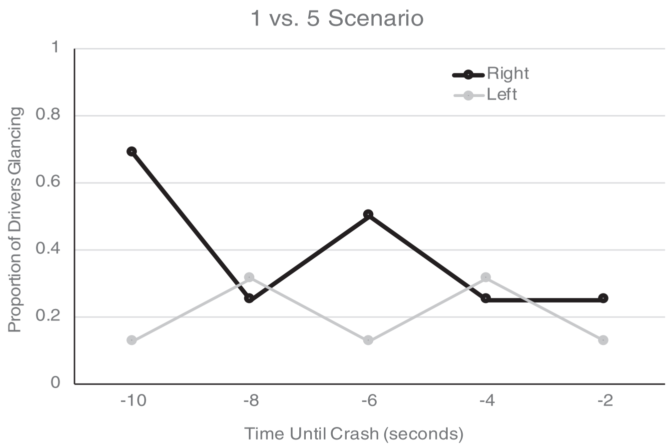

Fig. 4. Proportion of drivers glancing to the right (black) or the left (gray) extremity as a function of time until crash in seconds. [Note: negative time indicates the duration before a potential collision].

showing no measurable difference between the intervals where the pedestrians were invisible and the last interval where they were visible in both scenarios. Finally, we analyzed the participants' subjective ratings to a questionnaire item regarding ethics in driving: "Vehicles should try to protect as many pedestrians as possible in a crash or collision scenario." A Shapiro-Wilk normality test was conducted for each of the two groups, and both tests indicated significant violations of the normality assumption. Therefore, we used a non-parametric alternative of independent-samples *t*-test, the independent 2-group Mann–Whitney *U* test. Participants who steered left and hit only one pedestrian ($M = 4.43$) did not significantly differ in their rating than those who continued straight and hit five pedestrians ($M = 4.0$), independent 2-group $W = 42, p = .25$.

In Scenario 2, despite the option to maneuver past the five pedestrians altogether, only 62.5% of the drivers successfully evaded the group of five pedestrians (with a 95% CI of 35 to 83). This proportion was again significantly less than that of Navarrete et al. (2012) ($p = .002$). Their eye movements to the left and right sides during the 2 s immediately prior to the crash were no different from those during the control intervals. In Scenario 2, the number of drivers glancing to the left and right extremities did not vary across the different time intervals [both $p > .27$]. Similarly to Scenario 1, drivers who opted for the utilitarian outcome ($M = 4.38$) did not significantly differ in their rating regarding ethics in driving than those who did not opt for the utilitarian outcome ($M = 4.33$), independent 2-group $W = 30, p = 1$.

Fig. 5. Proportion of drivers glancing to the right (black) or the left (gray) extremity as a function of time until crash in seconds. [Note: negative time indicates the duration before a potential collision].

Our findings suggest that while people frequently choose utilitarian decisions in the typical, abstract manifestations of the Trolley Problems, drivers can fail to make utilitarian decisions in simulated driving environments representative of the restricted period of time they would have to make the same decision in the real world (two seconds). This finding by itself may not seem surprising, especially given a typical perception-response time of 1.5 s in driving scenarios (Muttart, 2018). However, this general perception-response time depends on a number of different factors. For our particular scenario, studies indicate that 85% of drivers can respond faster than 1.4 s when a previously obstructed hazard is first seen in the road and 95% can respond faster than 1.7 s. (Muttart, 2018). In summary, from an engineering perspective, two seconds seems like it is enough given the information on perception-response times in the literature (e.g., Muttart, 2018). But, we have seen with our experiment that 2 s is simply too little time to make a decision consistent with the choice drivers would make given a longer time frame.

We simply do not know how much time is enough to make ethical decisions while driving, but clearly need to know. This time will depend on a number of factors, some still to be discovered. From an ethical standpoint, we are now in a position to know that algorithms used in automated driving systems could make decisions for us that we cannot make when time is constrained and that we would prefer given a longer time to make the decisions. This question has not been raised to date with respect to more complex scenarios like those we have discussed and we think it deserves more attention.

Interestingly, the eye movement data show that the drivers are less likely to glance at the left and right sides of the road when under stress (in the safety-critical interval) than they are when not under stress. To put this slightly differently, the stress presumably induced when the driver discovers that he or she is about to strike five pedestrians causes the driver to become functionally fixated on the outcome, instead of looking for more alternatives (Orasanu, 1997). We now understand that the mental process of appraising a threat and the available countermeasures take place in the pre-frontal cortex (PFC). If the threat can be handled by means of well-practiced habits, a response is triggered at lower brain levels (the amygdala and the basal ganglia). When habitual responses are not applicable to the threat, as is presumably the case in our scenario, reasoning and recall of non-habitual behaviors are required. Unfortunately, and for reasons not fully understood, the stress response (which quickly triggers a host of changes in brain functions) inhibits activity in the PFC (Arnsten, 2009). These changes in brain function probably have survival value for "fight or flight" responses but may be maladaptive in the face of many modern threats such as the one we have in this scenario.

The results of the post-study questionnaire were not found to be statistically significant between the utilitarian and non-utilitarian drivers across any of the 16 items (see Appendix). The mean score for utilitarian drivers on item 6 on the questionnaire ('It is acceptable to risk harming others in order to save one's own life') is 1.73 compared to 1.94 for the non-utilitarian drivers. On a subsequent item ('It is right to harm one person on the road to save many people'), utilitarian drivers posted lower mean score of 2.87 compared to 3.35 for the non-utilitarian. While the results were not significant between utilitarian and non-utilitarian drivers in terms of subjective ratings, drivers tended to behave differently when put in situations of time-constrained ethical decision making. Future studies should perhaps focus more on the underlying mechanisms that control drivers behavior instead of solely relying on what they say.

Ultimately, human choices to make utilitarian decisions may rest on several cross-cultural, socio-economic and physiological factors (Costa et al., 2014; Terpstra et al., 1993; Vitell et al., 1993). The current study utilizes eye movements to demonstrate how a sample of college town drivers would respond to safety-critical situations requiring moral judgments under time pressure of 2 s. Inevitably, there remains much to be learned about the factors that need to be considered. However, from an implication perspective, there are a few key takeaways for major stakeholders including auto manufacturers, policy officials and the general public. Policy officials may consider the impacts of time duress on ethical decision making. Now we have data that tells us that our decisions given ample time do not necessarily align with our decisions under limited time. With an understanding of the delimited time limit of 2 s, traffic engineers could consider integrating design elements in the traffic infrastructure that minimize the occurrence of situations requiring a sudden, ethical outcome. Auto manufacturers may consider these findings in the development of AV moral algorithms to closely align with expectations. The drivers themselves may utilize these findings to better calibrate themselves regarding the limits on effective decision making under situations where outcomes need to be determined in under 2 s. A better understanding of temporal limits provides us with more effective pathways towards realizing desirable decision outcomes.

3.1. Limitations

There are several limitations with our approach. First, the study consists of only two scenarios. Generalizability across all situations will be limited. However, we chose to include what we thought was the most representative scenario to a philosophical thought experiment. Second, no measures of hazard mitigation involving steering or brake responses were collected in the current project and ultimately the ability to mitigate a potential threat is a critical component of what enables crash avoidance. Future research should incorporate drivers' steering and braking responses as behavioral measures that may provide further insights into drivers' intention in the driving environment involving ethical dilemmas under time constraints. Third, the study is conducted on a driving simulator and incorporates a small sample that may not be fully representative of the general population thereby placing some limits on generalizability to the open road. The simulator did offer a safe environment to collect data in a controlled environment. Fourth, previous research indicates that several factors that were not controlled in this study, such as demographic traits (including education, employment, and language) and socio-cultural and environmental characteristics, are likely to affect ethical decision making in drivers. Further research should explore the specific individual, demographic, cultural, or societal factors that impact ethical decision making for drivers both in traditional vehicles and those equipped with more advanced assistance systems. Last, the inclusion of a condition where drivers make decisions in a trolley scenario following a period of extended supervision or monitoring in a mid-level autonomous vehicle, would have allowed for a robust comparison of drivers' decision making under duress across systems with different levels of autonomy. This can be a future study.

4. Conclusions

n summary, the essence of the abstract Trolley Problem centers on human agency. Is an individual willing to let nature take its course and not intervene or, instead, to intervene and essentially save a number of lives? The answer from surveys is that most individuals were willing to intervene, to make what was essentially a utilitarian choice. But there was still the question of whether people would actually perform this way when given actual agency. Simulators allow researchers to study this. And indeed, when given enough time, individuals did make the utilitarian choice (Navarrete et al., 2012). Nevertheless, individuals are not always given enough time. In fact, our research suggests that drivers are routinely placed in time constrained situations where the decisions they make under such constraints are not consistent with the decisions they would make given more time. As a consequence, our research directly raises the question of whether algorithms in automated driving systems that more accurately reflect our choices should perhaps be allowed to make those choices for us as drivers, especially when we do not have the time we need to make the choices we presumably would prefer. Note that this flies directly in the face of a common sentiment. Most drivers do not want ethical decisions being made for them. What they do not know, in our opinion, is that they are placing themselves in situations where the decisions they are making are contrary to the decisions that they would have made given more time.

Funding

Portions of the study were supported by a grant from the US Department of Transportation Tier 1 SaferSim University Transportation Center (UTC) to Ohio State University (subcontracted to the University of Massachusetts Amherst) and from National Science and Engineering Research Council (RGPIN 2019-05304).

Author contribution statement

The authors confirm their contribution to the paper as follows: Study conception and design: Siby Samuel and Donald Fisher; Data Collection: Krishna Valluru and Siby Samuel; Analysis and Interpretation of results: Sarah Yahoodik, Yusuke Yamani and Siby Samuel; Draft Manuscript Preparation: Siby Samuel, Yusuke Yamani, Sarah Yahoodik and Donald Fisher. All authors reviewed the results and approved the final version of the manuscript. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the Volpe National Transportation Systems Center.

Appendix A. Results of post-study questionnaire

Items	Mean rating (1 = Strongly disagree, 5 = Strongly agree)			
	Utilitarian (N = 16)	Non-Utilitarian (N = 16)	t-value (df = 30)	p-value
Rules of road are the key in determining whether the action is right or wrong. (Ex:- Not overtaking school bus, yielding to the drivers in roundabouts, etc.)	4.60	4.59	0.05	0.96
It's fair to take driving allowances too, while driving on freeway. (Ex: Pulled over by police, observing speed limits, etc.)	3.87	3.41	1.25	0.22
You rely more on personal state of mind while making decisions on road. (For Ex: Fear, Frustration, Enjoyment, Loneliness, etc.)	2.40	2.29	0.27	0.79
Applying on-road rules too rigidly forces you towards a possible collision.	2.60	2.76	0.40	0.69
I get disconnected on road while driving in traffic with exceedingly congested public.	3.07	2.59	1.33	0.19
It is acceptable to risk harming others in order to save one's own life.	1.73	1.94	0.72	0.48
It is right to harm one person on road to save the lives of many people.	2.87	3.35	1.34	0.19
I feel that I can't trust the people and pedestrians on the road.	3.27	3.29	0.07	0.95
Following the vehicles in front of me when I am lost, but I find it difficult to completely trust them.	3.27	2.65	1.67	0.10
I prefer to do secondary tasks while driving in town.	2.07	2.24	0.48	0.64
Hand-held mobile phone conversation while driving doesn't have you preoccupied.	2.00	2.12	0.31	0.76
Vehicles should try to protect as many pedestrians as possible in a crash or collision scenario.	4.13	4.47	1.30	0.20
Long and forward roadway glances are not so important on a freeway drive.	2.13	1.76	1.06	0.30

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(*continued*)

Items	Mean rating (1 = Strongly disagree, 5 = Strongly agree)			
	Utilitarian (N = 16)	Non-Utilitarian (N = 16)	t-value (df = 30)	p-value
Emotions of driver play an important role in on-road decision making. (Ex: Driving Distraction, Road rage, etc.)	4.33	4.00	1.17	0.25
Whether you are calm, nervous, or hot-tempered, your emotions are affected by the interactive behavior of people on road.	3.80	3.59	0.51	0.61
Use of good judgment, common sense, courtesy, and safe driving rules are insignificant to ensure your safety and the safety of others.	1.53	1.71	0.44	0.67

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