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Research Article

Ethical decision-making in older drivers during critical driving situations: An online experiment

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ABSTRACT: The present study examined the impact of aging on ethical decision-making in simulated critical driving scenarios. 204 participants from North America, grouped into two age groups (18–30 years and 65 years and above), were asked to decide whether their simulated automated vehicle should stay in or change from the current lane in scenarios mimicking the Trolley Problem. Each participant viewed a video clip rendered by the driving simulator at Old Dominion University and pressed the space-bar if they decided to intervene in the control of the simulated automated vehicle in an online experiment. Bayesian hierarchical models were used to analyze participants' responses, response time, and acceptability of utilitarian ethical decision-making. The results showed significant pedestrian placement, age, and time-to-collision (TTC) effects on participants' ethical decisions. When pedestrians were in the right lane, participants were more likely to switch lanes, indicating a utilitarian approach prioritizing pedestrian safety. Younger participants were more likely to switch lanes in general compared to older participants. The results imply that older drivers can maintain their ability to respond to ethically fraught scenarios with their tendency to switch lanes more frequently than younger counterparts, even when the tasks interacting with an automated driving system. The current findings may inform the development of decision algorithms for intelligent and connected vehicles by considering potential ethical dilemmas faced by human drivers across different age groups.

KEYWORDS: ethical decision making, age-differences, utilitarianism, moral dilemmas, driver behavior, simulated driving, bayesian hierarchical model

1 Introduction

A typical roadway involves ambient traffic and other objects requiring the driver to make rapid decisions. In one rare but life-threatening circumstance, a driver may be forced to make ethical decisions, for example, deciding to collide with one or more pedestrians in a very short period. The Trolley Problem is a well-known paradigm for examining moral decision-making (Foot, 2002; Thomson, 1976). Numerous investigations have tried to examine the 'Trolley Problem' from the standpoints of vehicle and road safety (Bonnefon et al., 2016; De Moura et al., 2020; Goodall, 2014a; Himmelreich, 2018; Krügel and Uhl, 2022; Nyholm and Smids, 2016; Samuel et al., 2020; Yahoodik et al., 2021; Zhu et al., 2022). Recent studies have challenged the applicability of trolley instances to the moral design problem (Goodall, 2016; Himmelreich, 2018; Nyholm and Smids, 2016).

In recent years, the rising number of road traffic accidents and pedestrian fatalities has emphasized the need to address road safety concerns. While automated vehicles (AVs) can potentially reduce accidents caused by human error, ethical decision-making in complex scenarios remains a critical concern. Toward automated, connected and intelligent vehicles (Samuel et al., 2020), developing a decision algorithm that supports or even replaces, human decision-making in urgent and critical scenarios like ethically fraught scenarios is necessary. Integrating AVs into mixed traffic environments where remote connectivity among vehicles, pedestrians, and other road users is not yet established poses unique challenges, particularly when drivers face unavoidable accidents where they must make split-second moral choices. In the context of AVs in mixed-traffic environments, there is disagreement about the types of moral problems that AVs will face.

Some specific individual dilemmas in which causing harm to at least one person is inevitable, and a decision must be made concerning how to divide up damages or consequences of harm among multiple persons for whom the preferences are at odds (Goodall, 2014b; Gurney, 2015; Keeling, 2017, 2018). Others envision dilemmas that come up during normal driving. Consider the following scenario: The AV must decide how hard to brake while reaching a crossing because it is uncertain if a pedestrian would then step into the road (Himmelreich, 2018; Nyholm and Smids, 2016; Thornton, 2018). The key challenge is that of moral judgment. Prior research has substantiated that older individuals exhibit a decline in visual processing capabilities as well as a diminished allocation of attentional resources across the visual field (Hoffman et al., 2005; Madden, 2007; Parasuraman and Nestor, 1991). Correspondingly, performance in a driving simulator, assessed on speed, braking maneuvers, lane positioning, eye movements, and other measures, displayed comparatively poorer outcomes among older drivers than younger drivers (Perryman and Fitten, 1996). The authors contended that this

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disparity could be attributed to the lesser extent to which older drivers engage in visual scanning and exploratory behaviors relative to their younger counterparts during driving (Mourant and Rockwell, 1972). Furthermore, an additional study proposed that elderly individuals' responses to unexpected roadway events are characterized by delayed reactions due to a decline in executive control functions and multitasking proficiency (Gaspar et al., 2013).

The literature on cognitive aging states that normal aging is accompanied by two unique trajectories of changes in perceptual and cognitive abilities (Brown and Park, 2003). That is, processing capacity (working memory capacity, perceptual speed, etc.) declines as one age while domain-specific and domain-general knowledge and decision-making skills increase, which may offset the age-related declines in processing capacity. In the current study, the previous findings in older drivers are consistent with this framework in that older drivers were slower to respond to unexpected events due to decline in executive control functions (Gaspar et al., 2013) and more constricted visual scanning of the immediate roadway (Perryman and Fitten, 1996) perhaps due to their experience-driven processes (Mourant and Rockwell, 1972). However, how aging impacts their moral decision-making, which is a focus of the current study, remains unexplored.

Consider a vehicle moving down the road when a pedestrian (who was earlier undetectable) runs onto the road. The vehicle is unable to stop before actually colliding with the pedestrian. Only veering off the road toward the sidewalk can prevent pedestrians. However, four more pedestrians are walking on the sidewalk who would be impacted. Either killing four pedestrians on the sidewalk or one pedestrian is a moral choice in the sense that it necessitates moral consideration. Based on the framework of moral decision-making that focuses on processes, every moral dilemma is influenced by two conflicting principles: deontology and utilitarianism (Conway and Gawronski, 2013). Deontology emphasizes the ethical nature of an action, while utilitarianism argues that ethics are determined by the consequences of that action (Gray and Schein, 2012). Deontologists contend that harming others is wrong irrespective of the consequence. In contrast, utilitarians contend that harming others is acceptable if it leads to the well-being of a greater number of individuals. In situations of moral dilemmas, studies have repeatedly shown that individuals mainly utilize a utilitarian decision-making strategy (Faulhaber et al., 2019; Moll and Oliveira-Souza, 2007; Samuel et al., 2020; Yahoodik et al., 2021). Navarrete et al. (2012) investigated such a trolley problem in a dynamic virtual reality simulation and found that 89% of participants throughout conditions preferred the utilitarian outcome of pulling the toggle and killing one person over not doing anything and killing 5 persons. On the other hand, participants' subjective and psychological reactions in virtual reality environments closely reflect their experiences and behavior in real-life situations (Slater et al., 2006).

In a study conducted in a virtual environment to explore moral decision-making, researchers found that when participants faced time constraints, they were less inclined to make decisions that prioritized the well-being of younger and female avatars, as opposed to when they had more time to decide (Sütfeld et al., 2019). Another study, which investigated the interplay between intuitive and cognitive factors influencing moral judgments, observed that participants tended to focus their visual attention for longer periods on the individuals involved, especially when they had to choose between avatars of different genders (Skulmowski et al., 2014). Similarly, Samuel et al. (2020) argued that drivers often find themselves in situations with limited time for decision-making, which can lead to choices that differ from what they would make if they had more time to deliberate. This raises questions about whether algorithms in automated driving systems should always be expected to make decisions on behalf of drivers that accurately reflect their preferences, especially when time is a constraint.

While utilitarianism has been a widely discussed model for individual decision-making in safety-critical scenarios (Bonnefon et al., 2016), scientific evidence indicates that individuals consistently adopting a utilitarian approach has mainly been a subject of contemplative studies until recently. It remained uncertain whether individuals could consistently make utilitarian choices when faced with circumstances that compelled them to act on their commitments. In recent years, researchers have embarked on studies encompassing diverse demographics and cultures to investigate the ethical preferences concerning Autonomous Vehicle (AV) algorithms using the Trolley Problem as a framework (Awad et al., 2018; Bonnefon et al., 2016; Wang et al., 2022). Incorporating 'morality' into machine learning may pose technical and logistical challenges. However, the implications of drivers having to make ethically complex decisions in highly automated vehicle contexts are undeniable. Once vehicles reach Level 3 automation, drivers must take immediate control of the vehicle if the AV encounters a situation beyond its operational capabilities (SAE, 2018). Given that such takeover situations will most commonly occur in unusual and uncertain circumstances that the AV cannot handle, understanding the time it takes for drivers to respond in a manner consistent with their moral values, such as utilitarianism, is essential for comprehending the limitations of highly automated vehicles.

This study has two primary objectives aim to advance our understanding of ethical decision-making in driving contexts and inform the development of responsible decision algorithms in AV. The first objective is to investigate the decision-making patterns of drivers when confronted with a simulated Trolley Problem scenario under time constraints that resemble real-world traffic situations. By analyzing the choices made by drivers in morally complex circumstances, this research seeks to uncover the predominant ethical decision-making strategies employed by drivers. Specifically, the focus is on examining the interplay between utilitarian considerations and deontological principles within the given time limitations. The second objective is to explore potential age-related differences in decision-making abilities within morally challenging driving scenarios. By comparing the decision-making processes of younger and older drivers, this study aims to identify any variations that may arise due to perceptual and cognitive factors associated with aging. Thus, it is hypothesized that drivers will predominantly adopt a utilitarian decision-making strategy, prioritizing the greater good even in ethically complex situations. Additionally, it is hypothesized that younger drivers may choose utilitarian decisions more than older drivers because younger drivers will perceive the immediate roadway more accurately than older drivers.

2 Experimental design and procedures

The subsequent sections provide a comprehensive overview of the experimental design and procedures employed in this study.

2.1 Participants

A total of 290 participants from North America were recruited for this study. However, 86 participants were excluded as they attempted the predetermined 'catch-trials', which involved either responding when no pedestrian was present or failing to respond in any of the video trials during the study. Therefore, the final participant pool consisted of 204 participants as shown in Table 1. All recruited participants provided informed consent held valid driver's licenses and reported normal or corrected-to-normal visual acuity. A remuneration of 5 Canadian Dollar (CAD) was provided to each participant. The study protocol was reviewed and approved by the University of Waterloo Research Ethics Board (ORE#44255).

Table 1 Demographic characteristics of participant groups

Age group	Total participants	Mean age (years)	Standard deviation (years)	Male participants	Female participants
Young	102	24.7	3.5	38	64
Older	102	71.0	5.7	59	43

2.2 Equipment

This study employed a medium-fidelity desktop driving simulator (Carnetsoft, the Netherlands) to simulate and capture the driving scenarios. Due to the prevailing COVID-19 rules and regulations, the study was conducted online. The simulated video trials and survey questions were uploaded to Qualtrics using JavaScript. The Qualtrics survey was integrated with the Prolific platform to recruit participants.

2.3 Simulated driving scenarios and study design

The driving simulator was employed to model and record 12 situations to represent each factorial combination of the following independent variables.

The scenarios varied based on the presence of pedestrian avatars, their location in either the right-hand lane (i.e., towards the vehicle's path) or the neighboring left-hand side lane, and the inclusion of an additional pedestrian avatar positioned in the opposing lane.

Time-to-collision (TTC): Pedestrian avatars arrived 1, 2, or 3 s prior the simulated vehicle's path crossing the mid-block pedestrian crossing.

Placement of pedestrians: A group of 5 pedestrians came into view in either the right or left lanes, as depicted in Figs. 1a and 1b.

Alternative pedestrian: Fig. 1a depicts a scenario where no pedestrians were present in the oncoming traffic lane during the second interval. Contrarily, as illustrated in Fig. 1b, a solitary pedestrian is positioned in the lane directly opposing a bunch of 5 pedestrians.

The videos depicted the interior of a car's cabin, depicting the car traveling in the right-hand side lane on a 4-lane countryside road (Fig. 1). The fog created reduced visibility, and no other vehicles were present along the roadway. Around 30 s into the video started, the virtual car approached a pedestrian crossing in the middle of the block. Five seconds before reaching the crosswalk, a sign displaying 'Pedestrian Crossing' became visible. Before reaching the pedestrian crossing, a group of pedestrians materialized and started moving towards the middle of the roadway. The video paused before any pedestrians were impacted. Accordingly, the study employed a 2 (group placement) × 2 (alternative pedestrian presence) × 3 (time-to-collision) repeated-measures design.

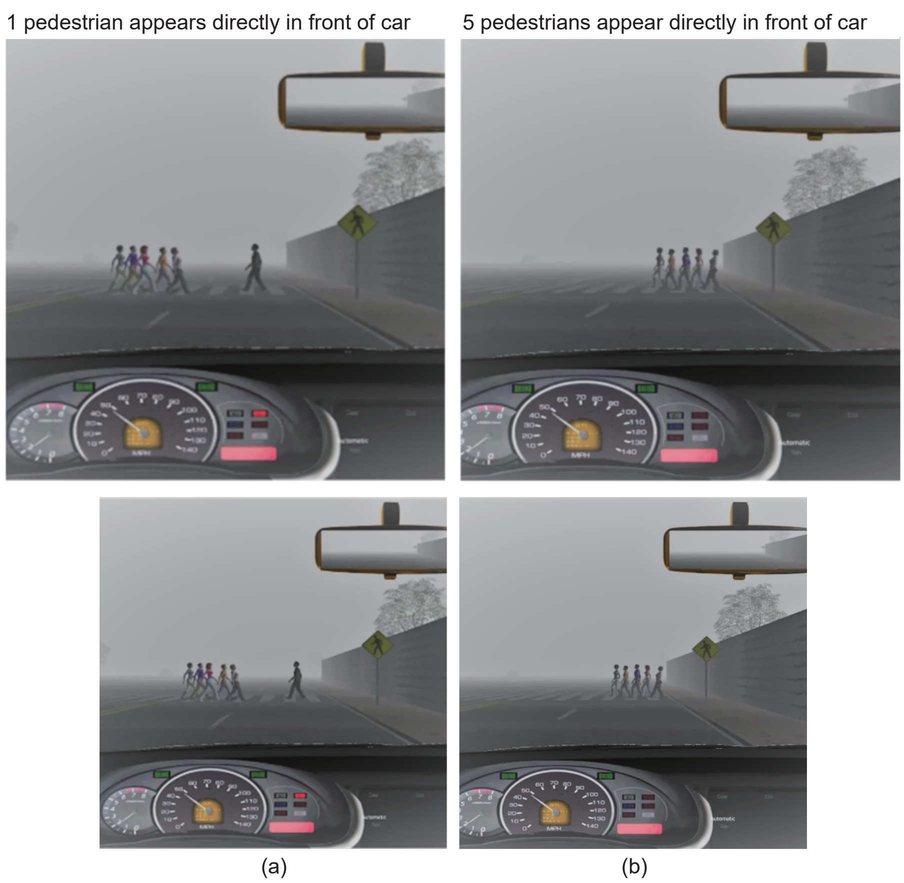

Fig. 1 An ethical decision scenario example: (a) 1 pedestrian become visible directly ahead of the car's path, and a group of 5 pedestrian avatars appears in the adjacent lane; (b) a group of 5 pedestrians appears directly ahead of the car's path.

2.4 Catch trials

Participants were presented with four catch videos anda set of 12 ethical decision scenarios. The catch trials were similar to the experimental video content, except no pedestrians were on the crosswalk. These trials were designed to pinpoint participants who did not refrain from responding, indicating a failure to comply with the provided instructions.

2.5 Procedure

This study was conducted online through Prolific's participant recruitment system (www.prolific.co). Participants were directed to a platform hosted by Qualtrics and instructed to read the following instructions.

"Imagine that you are operating a car with limited automated features. The car automatically keeps in its lane and retains the posted speed limit, but it cannot avoid unexpected obstacles. On the roadway, obstacles may appear during this task. You will be responsible for overriding automation when essential. If you want to continue straight, do not press any key on the keyboard. If you wish to change lanes to the left, press the spacebar key. Do not press the space bar if you do not believe a maneuver is required. The trial will end when you press the space bar, and the subsequent trial will begin automatically."

After confirming that the participants had read the instructions, the trial started to be recorded. The order in which the 16 simulated video trials (consisting of 12 recorded trials and 4 catch trials) were presented was random. Every trial lasted 30 s. The study focuses on two dependent variables, choice response and response time. The choice response is a response of either pressing the space bar or not pressing the space bar was recorded for each trial. Response time is the interval between the beginning of each video and their choice response in scenarios where participant response was recorded. Following the completion of the trials, participants were asked to rate on a scale from one (strongly agree) to five (strongly disagree) the viability of a utilitarian approach to ethical decision-making (prioritizing saving more lives even at the cost of others) (Samuel et al., 2020). The duration of the study was approximately 15 min.

2.6 Data cleaning

Data were examined and cleaned to minimize the likelihood of erroneous or careless responses from participants. Although participants were automatically excluded from analysis if they responded to the catch trial, on closer examination, a large proportion of participants (24 younger and one older) pressed the space bar for every trial. This lack of response variation may indicate that they did not understand the study instructions and were pressing the space-bar every time they saw a pedestrian avatar. These participants were excluded from the data analysis. As such, data from 78 younger and 101 older participants were included in the final analysis.

2.7 Data analysis

Researchers used a two-level Bayesian hierarchical model using Markov chain Monte Carlo (MCMC) sampling algorithm to estimate parameters, allowing the model to account for individual differences in the data. A hierarchical logistic regression model was constructed to predict a binary decision outcome (stay in the lane vs. change the lane) from the three predicting variables all nested within participants and Age, where Age was modeled as a fixed-effect factor at the first level and the other predicting variables were modeled as fixed-effect factors at the second level. The rstanarm package in R was used to fit the binary response data to the hierarchical logistic regression model (Muth et al., 2018). Weakly informed priors were used, with 8,000 iterations for each of the four MCMC chains.

We calculated 90% Bayesian credible intervals (BCIs) for each regression parameter estimate. Credible intervals reflect the range of posterior values a parameter estimates to lie. If the credible interval for the parameter estimation falls exclusively a positive or negative range (i.e., the interval does not contain zero), it provides evidence for the effect of interest. BCIs are recommended to be calculated at the 90% level (as opposed to the typical 95% level seen in frequentist confidence intervals) due to the lack of stability at the very ends of the posterior distribution (Muth et al., 2018).

3 Results

Examining the outcomes unveiled several noteworthy findings about the positioning of pedestrians, variations in age, Time-to-Collision (TTC), and their interrelationships. In all cases, the parameters demonstrated $\widehat{R} < 1.1$, signifying robust convergence. $\widehat{R}$ measures the ratio of variances among and within the chains, and an $\widehat{R}$ value near 1 implies that the patterns across the chains are virtually identical, aside from random noise. The full parameter estimations for all effects and interactions are reported in Table 2.

Data indicate evidence for the main effect of the pedestrian placement manipulation, indicating that, when pedestrians were in the right lane, participants pressed the space-bar to intervene the automated driving system and change lane for roughly 95% of the scenarios compared to 33% in the scenarios that participants were impacting either 1 or no pedestrian avatar, slope = –5.0, [–7.1, –2.9]). This response pattern is consistent with utilitarianism because they were likelier to choose an option to minimize a loss (e.g., choosing an option with fewer pedestrian avatars). Additionally, age also credibly influenced participants' decisions. Young participants (aged 18–30) were more likely to press the space-bar (M = 0.6, SD = 0.4) than older participants (M = 0.6, SD = 0.4), across all conditions, slope = –1.9, 90% BCI = [–3.7, –0.3].

Surprisingly, the data gave no evidence for the interaction effects, including those involving Age as a factor. Except for the main effect of Age, older participants' ethical decision-making patterns are no different from those of young participants, even under high time pressure. Overall, data argue against the prediction that older drivers would make less utilitarian but more random decisions due to age-related decline in processing capacity than young drivers. However, we also failed to replicate the main effect of TTC and Placement × TTC interaction effect as found in Yahoodik et al. (2021), perhaps due to increased variability of a sample of older participants. We repeated the analysis separately for young and older participants' data to confirm this.

For younger participants, the data strongly support Placement influencing decisions, indicated by a slope of –4.4 (90% BCI = [–6.0, –2.9]), aligning with the utilitarian responses presented in Table 3. Notably, participants expressed a slightly increased inclination to change lanes as Time to Contact (TTC) decreased, with a slope of 1.0 (90% BCI = [0.3, 1.8]). However, the interaction effect was not deemed credible (slope = –0.8, 90% BCI = [–1.6, 0]). Similarly, older participants also exhibited evidence supporting utilitarian decision-making, with a slope of –3.3 (90% BCI = [–4.8,

Table 2 Posterior parameter estimation summary table for the omnibus analysis

	Mean	SD	5%	95%
Intercept	4.2	1.2	2.3	6.2
Placement of pedestrians	−5.0	1.3	−7.1	−2.9
Alternative pedestrian	0.0	1.0	−1.6	1.7
TTC	1.0	0.6	0.0	2.0
Age	−1.9	1.0	−3.7	−0.3
Placement of pedestrians*Alternative pedestrian	−0.3	1.1	−2.0	1.4
Placement of pedestrians*TTC	−1.0	0.6	−2.1	0.1
Placement of pedestrians*Age	0.9	1.1	−0.9	2.8
Alternative pedestrian*TTC	0.6	0.6	−0.4	1.6
Alternative pedestrian*Age	−1.2	1.1	−3.1	0.5
TTC*Age	0.0	0.5	−0.8	0.9
Placement of pedestrians*Alternative pedestrian*TTC	−0.9	0.6	−1.9	0.2
Placement of pedestrians*Alternative pedestrian*Age	1.3	1.2	−0.6	3.3
Placement of pedestrians*TTC*Age	0.2	0.6	−0.7	1.2
Alternative pedestrian*TTC*Age	0.3	0.6	−0.8	1.3
Placement of pedestrian*Alternative pedestrian*TTC*Age	0.1	0.7	−1.0	1.2

Note: * interaction between the variables.

Table 3 Posterior parameter estimation summary table for young participants

	Mean	SD	5%	95%
Intercept	3.4	0.9	2.0	4.9
Placement of pedestrians	−4.4	1.0	−6.0	−2.9
Alternative pedestrian	−0.6	0.8	−1.9	0.7
TTC	1.0	0.5	0.3	1.8
Placement of pedestrians*Alternative pedestrian	0.4	0.8	−1.0	1.8
Placement of pedestrians*TTC	−0.8	0.5	−1.6	0.0
Alternative pedestrian*TTC	0.6	0.5	−0.2	1.3
Placement of pedestrians*Alternative pedestrian*TTC	−0.6	0.5	−1.4	0.2

Note: * interaction between the variables.

−1.9]). Older participants tended to press the space-bar less frequently when TTC was shorter, with a slope of 1.2 (95% BCI = [0.5, 2.0]), as detailed in Table 4. The most significant decrease in response frequency occurred between 1 and 2 second TTCs (0.26 vs. 0.34, respectively), aligning with utilitarian considerations (slope = −1.0, 95% BCI = [−1.8, 0.2]). The remaining effects were not considered credible.

4 Discussion

The present experiment examined whether decision-making behaviors vary between groups of young and older individuals in ethically fraught driving scenarios rendered by a driving simulator. In particular, the participants monitored dynamic driving scenes, assuming that they were piloting an automated driving system where the presence and placement of pedestrians were systematically manipulated within each participant. Additionally, we manipulated TTC to induce time pressure on their decision-making using 1, 2, and 3 s time intervals.

Using a sample size substantially larger than the previous work (Yahoodik et al., 2021, the current data contrasts the previous data in two unique ways. First, by looking only at young participant data, we largely replicated the effect of Placement and TTC as reported in Yahoodik et al. (2021). The current participants made responses consistent with utilitarianism and that they made less responses indicating their intention to change the lanes, confirming the first hypothesis. This result and the previous

Table 4 Posterior parameter estimation summary table for older participants

	Mean	SD	5%	95%
Intercept	1.7	0.8	0.5	3.0
Placement of pedestrians	−3.3	0.9	−4.8	−1.9
Alternative pedestrian	−0.8	0.8	−2.1	0.5
TTC	1.2	0.5	0.5	2.0
Placement of pedestrians*Alternative pedestrian	0.5	0.9	−1.0	2.0
Placement of pedestrians*TTC	−1.0	0.5	−1.8	−0.2
Alternative pedestrian*TTC	0.7	0.5	−.1	1.4
Placement of pedestrians*Alternative pedestrian*TTC	−0.6	0.5	−1.4	0.3

Note: * interaction between the variables.

research imply that young drivers are likely to make decisions consistent with their utilitarian view of the ethical dilemma, especially when TTC is long. Dual-process theories of cognition such as two systems of reasoning (Kahneman and Frederick, 2002) can describe how drivers make decisions fast and automatic in some situations (e.g., when TTC is short) and slowly and elaboratively in others (e.g., when TTC is long). System 1 refers to an intuitive system that relies on effortless pattern matching and heuristics, while System 2 is an analytical system that employs effortful, deliberate, and rational processes. System 1 thus supports naturalistic decision-making, especially when an environment requires rapid selection of responses under high workload with reliable feedback from the environment (e.g., recognition-primed decision-making (RPD). Within this theoretical framework, the current results for young participants are best explained by processes involving System 2 than System 1, in that their ethical decision-making is slow and elaborative behavior than fast and automatic. However, this interpretation would require additional experimentation because the current data did not give strong evidence for the interaction between Placement and TTC while the previous work (Yahoodik et al., 2021) did.

When we entered data from older participants to the overall model, the effect of Placement persisted without interacting with Age, indicating that the young and older participants exhibited similar decision-making patterns, both consistent with the utilitarianism. Furthermore, Age did not interact with any of the effects of the manipulations in this study, providing evidence that older drivers may continue to possess the ability to make rapid decisions in ethically fraught scenarios similarly to their young counterparts. Therefore, the results do not support the second hypothesis. The cognitive aging literature consistently find mainly two different trajectories of age-related changes in perceptual and cognitive processes. Briefly, as individuals' age, their sensory, perceptual, and processing capacities decline whereas their domain-specific and domain-general knowledge increases, which allows them to offset age-related loss in tasks that they have more experience on. Relating these age-related changes to the current finding, older individuals may activate System 1 processes by rapidly matching the perceived road scenes, despite their slower sensory and perceptual processing speed, with those stored in their long-term memory and quickly activating appropriate responses without deliberate processes. This view is further supported by the main effect of TTC and the Placement by TTC interaction in older participants. Older participants were less likely to indicate their intention to change lanes in scenarios where changing lanes would violate utilitarianism. This pattern was not observed in young drivers in the current study and in Yahoodik et al. (2021).

How did young and older participants make their ethical decisions similarly in the current experiment? Two different mechanisms for young and older individuals may operate in ethical decision-making. For young individuals, decision-making in driving scenarios must largely rely on elaborative and resource-demanding processes due to the lack of or limited driving experience. This implies that young individuals are more likely to process information coming from the driving scene in a bottom-up, or data-driven, manner in which they perceive and construct their mental models of the dynamic driving environment more based on the incoming data. The interaction between the placement of pedestrians and TTC found in Yahoodik et al. (2021) lend partial support to this, showing that the participants' decisions became more random and less utilitarian as their time budget decreased. The shorter TTC, the less time to employ the elaborative perceptual-cognitive processes to support ethical decision-making. On the other hand, older individuals are likely to employ fast and automatic responses without needing to recruit cognitive resources for elaborative processes. That is, older individuals may make decisions in a top-down, or knowledge-driven, manner. The rapid pattern matching of an immediate roadway with information stored in their long-term memory would allow them to generate the most appropriate responses based on their driving experience.

The current experiment faces several caveats. First, some of the 90% BCI marginally include zero, indicating that the respective parameter estimates are less reliable, which would require a stronger experimental manipulation of the independent variables. Second, the ethical decision-making process for young and older drivers should be further examined in a driving simulator to validate the current findings using a driving task. Controlling a vehicle itself may consume attentional resources, presumably at different rates for young and older drivers due to their different driving experience, affecting their ethical decision-making. Partly addressing this concern, we ran a driving simulator experiment which manipulated TTC and showed that drivers do make utilitarian decisions in the pattern mirroring that of Yahoodik et al. (2021). However, a driving simulator experiment with both young and older drivers is necessary to examine the current hypothesis in a controlled setting.

5 Conclusions

In conclusion, the current study partially replicate Yahoodik et al. (2021) confirms that individuals in the online experiment tend to make utilitarian decisions, with older individuals exhibiting similar decision-making patterns. The findings were interpreted within the framework of dual-process theories and the cognitive aging literature.

Practically, it suggests that designers of a decision-making algorithm, especially those for ethically challenging scenarios (like those we used in the current study), should consider tailored interfaces. Supporting top–down processes for young drivers and bottom–up processes for older drivers can enhance age-specific information processing critical for ethical decisions-making behind the wheel.

However, implementing ethically appropriate decisions necessitate advanced technologies, including smart sensors and AI/ML algorithms, alongside potential wireless communication between intelligent vehicles and pedestrians. Intelligent vehicles, when interconnected with nearby entities, can detect potential moral decision scenarios, prompting them to slow down. This provides drivers with additional time to make informed ethical decisions.

Replication and data sharing

The replication package for this study is accessible for download at https://osf.io/fg39j. This package contains organized files obtained by processing the raw data CSV files.

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Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

References

Awad, E., Dsouza, S., Kim, R., Schulz, J., Henrich, J., Shariff, A., *et al*., 2018. The moral machine experiment. Nature, 563, 59–64.

Bonnefon, J. F., Shariff, A., Rahwan, I., 2016. The social dilemma of autonomous vehicles. Science, 352, 1573–1576.

Brown, S. C., Park, D. C., 2003. Theoretical models of cognitive aging and implications for translational research in medicine. Gerontologist, 43, 57–67.

Conway, P., Gawronski, B., 2013. Deontological and utilitarian inclinations in moral decision making: a process dissociation approach. J Pers Soc Psychol, 104, 216–235.

De Moura, N., Chatila, R., Evans, K., Chauvier, S., Dogan, E., 2020. Ethical decision making for autonomous vehicles. In: 2020 IEEE Intelligent Vehicles Symposium (IV), 2006–2013.

Faulhaber, A. K., Dittmer, A., Blind, F., Wächter, M. A., Timm, S., Sütfeld, L. R., *et al*., 2019. Human decisions in moral dilemmas are largely described by utilitarianism: Virtual car driving study provides guidelines for autonomous driving vehicles. Sci Eng Ethics, 25, 399–418.

Foot, P., 2002. The problem of abortion and the doctrine of the double effect. In: *Virtues and Vices*. Oxford: Oxford University Press, 19–32.

Gaspar, J. G., Neider, M. B., Kramer, A. F., 2013. Falls risk and simulated driving performance in older adults. Aging Res, 2013, 356948.

Goodall, N., 2014a. Ethical decision making during automated vehicle crashes. Transp Res Rec, 2424, 58–65.

Goodall, N. J., 2014b. Machine ethics and automated vehicles. In: *Road Vehicle Automation Lecture Notes in Mobility*. Berlin: Springer International Publishing, 93–102.

Goodall, N. J., 2016. Can you program ethics into a self-driving car? IEEE Spectr, 53, 28–58.

Gray, K., Schein, C., 2012. Two minds vs. two philosophies: Mind perception defines morality and dissolves the debate between deontology and utilitarianism. Rev Philos Psychol, 3, 405–423.

Gurney, J. K., 2015. Crashing into the unknown: An examination of crash-optimization algorithms through the two lanes of ethics and law. Alb L Rev, 79, 183.

Himmelreich, J., 2018. Never mind the trolley: The ethics of autonomous vehicles in mundane situations. Ethical Theory Moral Pract, 21, 669–684.

Hoffman, L., McDowd, J. M., Atchley, P., Dubinsky, R., 2005. The role of visual attention in predicting driving impairment in older adults. Psychol Aging, 20, 610–622.

Kahneman, D., Frederick, S., 2002. Representativeness revisited: attribute substitution in intuitive judgment. In: *Heuristics and Biases: The Psychology of Intuitive Judgment*. New York: Cambridge University Press, 49–81.

Keeling, G., 2017. Against leben's rawlsian collision algorithm for autonomous vehicles. In: 3rd Conference on Philosophy and Theory of Artificial Intelligence, 259–272.

Keeling, G., 2018. Legal necessity, Pareto efficiency & justified killing in autonomous vehicle collisions. Ethical Theory Moral Pract, 21, 413–427.

Krügel, S., Uhl, M., 2022. Autonomous vehicles and moral judgments under risk. Transp Res Part A Policy Pract, 155, 1–10.

Madden, D. J., 2007. Aging and visual attention. Curr Dir Psychol Sci, 16, 70–74.

Moll, J., Oliveira-Souza, R., 2007. Moral judgments, emotions and the utilitarian brain. Trends Cogn Sci, 11, 319–321.

Mourant, R. R., Rockwell, T. H., 1972. Strategies of visual search by novice and experienced drivers. Hum Factors, 14, 325–335.

Muth, C., Oravecz, Z., Gabry, J., 2018. User-friendly Bayesian regression modeling: A tutorial with rstanarm and shinystan. TQMP, 14, 99–119.

Navarrete, C. D., McDonald, M. M., Mott, M. L., Asher, B., 2012. Virtual morality: Emotion and action in a simulated three-dimensional "trolley problem". Emotion, 12, 364–370.

Nyholm, S., Smids, J., 2016. The ethics of accident-algorithms for self-driving cars: an applied trolley problem? Ethical Theory Moral Pract, 19, 1275–1289.

Parasuraman, R., Nestor, P. G., 1991. Attention and driving skills in aging and Alzheimer's disease. Hum Factors, 33, 539–557.

Perryman, K. M., Fitten, L. J., 1996. Effects of normal aging on the performance of motor-vehicle operational skills. J Geriatr Psychiatry Neurol, 9, 136–141.

Samuel, S., Yahoodik, S., Yamani, Y., Valluru, K., Fisher, D. L., 2020. Ethical decision making behind the wheel–A driving simulator study. Transp Res Interdiscip Perspect, 5, 100147.

Skulmowski, A., Bunge, A., Kaspar, K., Pipa, G., 2014. Forced-choice decision-making in modified trolley dilemma situations: A virtual reality and eye tracking study. Front Behav Neurosci, 8, 426.

Slater, M., Antley, A., Davison, A., Swapp, D., Guger, C., Barker, C., *et al*., 2006. A virtual reprise of the Stanley Milgram obedience experiments. PLoS One, 1, 1–10.

Sütfeld, L. R., Ehinger, B. V., König, P., Pipa, G., 2019. How does the method change what we measure? Comparing virtual reality and text-based surveys for the assessment of moral decisions in traffic dilemmas PLoS One, 14, 1–14.

SAE, 2018. Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles J3016_201806. https://doi.org/10.4271/J3016_201806

Thomson, J. J., 1976. Killing, letting die, and the trolley problem. Monist, 59, 204–217.

Thornton, S. M., 2018. Autonomous vehicle motion planning with ethical considerations. Stanford, USA: Stanford University.

Wang, H., Wang, A., Su, F., Schwebel, D. C., 2022. The effect of age and sensation seeking on pedestrian crossing safety in a virtual reality street. Transp Res F, 88, 99–110.

Yahoodik, S., Samuel, S., Yamani, Y., 2021. Ethical decision making under time pressure: An online study. Proc Hum Factors Ergon Soc Annu Meet, 65, 601–605.

Zhu, A., Yang, S., Chen, Y., Xing, C., 2022. A moral decision-making study of autonomous vehicles: Expertise predicts a preference for algorithms in dilemmas. Pers Individ Differ, 186, 111356.

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