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Using Simulation-software-generated Animations to Investigate Attitudes Towards Autonomous Vehicles Accidents

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Abstract

Road accidents involving autonomous vehicles are inevitable and have the potential to damage the public's confidence in the technology and ultimately result in its disuse. It's important to understand how people react to such incidents and the influencing factors of blame attribution and trust restoration. Research in this field has started to grow but faces a huge methodological challenge, which is to develop high-fidelity experimental stimuli as realistic representations of accident scenarios in order to elicit valid reactions from human participants. The present paper reviews and evaluates several existing methods used in the research field before proposing an alternative method of generating animated accident sequence using driving simulation software. It is argued that this method strikes a good balance of fidelity, versatility and cost-effectiveness. We also present some preliminary evidence for the effectiveness of variable manipulation using such a methodology.

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1. Introduction

The current paper describes a method developed to investigate human judgments relating to road accidents involving autonomous vehicles (AVs) which allows mass scale and remote data collection in a cost-effective way. In order to elicit valid reactions from the human participants, high-fidelity representations of the accidents sequence need to be constructed as part of the experimental stimuli. However, the pursuit of realism often comes with a price: high-

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fidelity materials (e.g., driving simulations) are often costly to develop and studies can be very cumbersome and resource intensive to conduct. This makes data collection very time-consuming which often limits the sample-sizes of studies with implications for power and effect sizes. Under-powered human studies have already been a prevalent issue in the research area of autonomous driving, which was exacerbated by the COVID-19 pandemic due to its prohibition of laboratory-based testing of human participants during lockdown and related periods within many countries. The post-COVID world will likely be characterized with reduced face-to-face contact and increased online activities. The research presented within the current paper proposes a solution for generating experimental stimuli that are economical to produce but also easy to disseminate online. To exemplify, the method will be discussed in the context of research on autonomous driving accidents. But it has the potential to be deployed to wider research areas with a general interest in attitudes towards AVs.

We are on the verge of introducing autonomous vehicles (AVs) to public roads (and allowing some that have self-driving capabilities to be driverless at least some of the time) but there are still tremendous legal, social and psychological barriers. One of the biggest concerns relates to automation failure and accidents [1]. Autonomous driving technologies might be superior compared with (most) human drivers but they are and will not be perfect and accidents will be inevitable, which introduces tremendous legislative challenges in terms of liability distribution [2]. Accidents as well as any adverse experience with an AV (e.g., system failure, near-misses, etc.) may also erode human trust in the technology and prohibit its adoption [3], [4]. Therefore, it is vital to understand the public's reactions to traffic incidents involving AVs from a psychological stand point, including moral appraisals, judgments of blame, the loss of trust and its restoration, to inform legislation and policy making, so that they are conducive to the proliferation of such technology.

The research area faces some non-trivial methodological challenges, one of which is to present the human participants with convincing, realistic experimental stimuli that can yield valid results. Unlike research in other areas of human-robot/human-automation interaction, where attitudes like trust and acceptability can be measured after real interaction with the system [5], it is impractical (and unethical) to subject a human participant to experiencing or witnessing real accidents. It is possible to present video footage of real traffic incidents but given the rarity of such events, it's difficult to find video clips that can naturally meet the requirements of the objectives for a particular experiment with appropriate experimental control. Also, it's very restricting in how and how many variables can be independently manipulated in real-life footage. Finally, there are ethical concerns with subjecting human participant to viewing materials which could potentially be distressing. An alternative method is to let participants experience a simulated traffic incident in the seat of a driving simulator. While this method can potentially achieve a high level of realism, it is logistically demanding both for the development of the experimental materials and the data collection process. Consequently, the research in this field has resorted to alternative methods of representing accident scenarios including vignettes, animations and virtual reality (VR).

The following section will provide a review of these methods, illustrated by exemplar studies. Comparisons will also be made over the dimensions of fidelity (i.e., the exactness or faithfulness of the representation of an accident scenario to what have happened or what could happen in the real world), versatility (i.e., the ease with which aspects of the accident scenario can be parametrically, independently manipulated and controlled) and logistic demand (i.e., how costly it is to develop the stimuli and to conduct the experiment). The next section will introduce an alternative method of constructing and presenting accident scenarios, which is to use driving simulation software to generate animation video clips. We argue that this method, developed during the COVID-19 pandemic, strikes a good balance between fidelity and practicality and is a good solution to representing accident scenarios in a post-pandemic world.

2. A Comparison of Existing Methods

2.1. Vignette studies

Vignette studies (short textual stories with or without pictorial illustrations) have been a popular method of probing attitudes, beliefs and judgments in psychological experiments and surveys [6]–[8]. There are several advantages associated with this methodology, economy being one – they are easy to produce and disseminate, whether through paper or online media. Each vignette story is relatively short therefore multiple scenarios can be tested in one experiment, which renders a rich diversity and representativeness of situations. This is particularly beneficial for studies of exploratory nature. It's also very easy to control, manipulate and isolate variables with vignettes. Text can be varied freely and easily without affecting other aspects of the stimuli. One might question the fidelity of a vignette story – after all they are just a semantic abstraction of an event, which leaves much room for the reader's interpretation and imagination. However, to the extent that the information of a road accident will be largely disseminated through text-based media (e.g., the press, social media, official report, etc), findings elicited by vignette stories arguably bear some level of ecological validity.

Given those benefits, the vignette studies have been the dominant method in the research area of autonomous vehicles accidents (see Table 1). For example, in what's called the "moral machine experiments", Awad et al. [9] used randomly-generated text-based scenarios with cartoon picture illustrations to collect people's preferences of AV decisions in moral dilemmas (e.g., killing three elderly pedestrians who are crossing the road illegally versus killing three young passengers of the vehicle). Short vignettes stories are especially fitting to the purpose of this type of studies because abstraction facilitates moral judgments [10].

Table 1. A summary of methodologies used in research on judgments relating to autonomous vehicles accidents

Literature	Type of Stimuli	Source of Scenarios	Key Dependent measures
Awad et al., 2018 [9]	Vignettes with pictorial illustrations	Fictional	Moral decisions
Awad et al., 2020 [11]	Vignettes	Fictional	Blame, responsibility
Bennett et al., 2020 [12]	Vignettes	Fictional	Responsibility
Bonnefone et al., 2016 [13]	Vignettes with pictorial illustrations	Fictional	Moral decisions
Franklin et al., 2021 [14]	Vignettes	Fictional	Blame
Hong et al., 2020 [15]	Vignettes	Based on real incident	Responsibility
Hong et al., 2021 [16]	Vignettes	Fictional	Perception of the driver (e.g., trustworthiness, friendliness etc.), responsibility.
Kallioinen et al., 2021 [17]	VR animations (by UNITY)	Fictional	Moral decisions
Liu et al., 2019 [18]	Vignettes	Fictional	Affect, perceived severity, acceptability of the crash
Liu & Du, 2021 [19]	Vignettes	Fictional	Affect, perceived severity, acceptability of the crash, blame
McManus & Rutchick, 2019 [20]	Vignettes	Fictional	Responsibility
Pöllänen et al., 2020 [21]	Vignettes	Fictional	Blame
Zhang et al., 2021 [22] Zhang et al., (pre-print)	Vignettes with pictorial illustrations.	Fictional/based on real incidents	Blame, Trust
Zhang et al., (manuscript under preparation)	Animations (generated by simulation software)	Based on real incidents	

Similar methods were also used to elicit judgments of blame and responsibility relating to accidents involving AVs [11], [12], [14]–[16], [19]–[21]. In one of our own studies [22], six vignette stories of traffic incidents with various level of severity (Figure 1) were presented to human participants featuring a wide range of traffic conditions – from urban, suburban to rural roads. They also varied in complexity – from situations where a pedestrian and an animal simply jumped out in front of a moving autonomous vehicle, to more complex ones where the vehicle makes attempts to circumvent a stopped bus but conflicts with a pedestrian walking out from behind the bus. The participants were asked to focus on the movement of the target vehicle (the blue car) in every story, which consisted of two parts (Figure 2): The first part described an emergency situation, which was coupled with one of three versions of the second part, which described the reaction of the target vehicle and the ensuing consequences. The three versions of the second part corresponded to three levels of outcome severity – near-miss, minor accident and major accident. Participants were then asked questions relating to their judgments of blame (i.e., the extent to which they thought the driver/operator of the target vehicle or other road users should be blamed for the incident) and trust (i.e. the extent to which they would trust the driver/operator of the target vehicle to operate safely in the future).

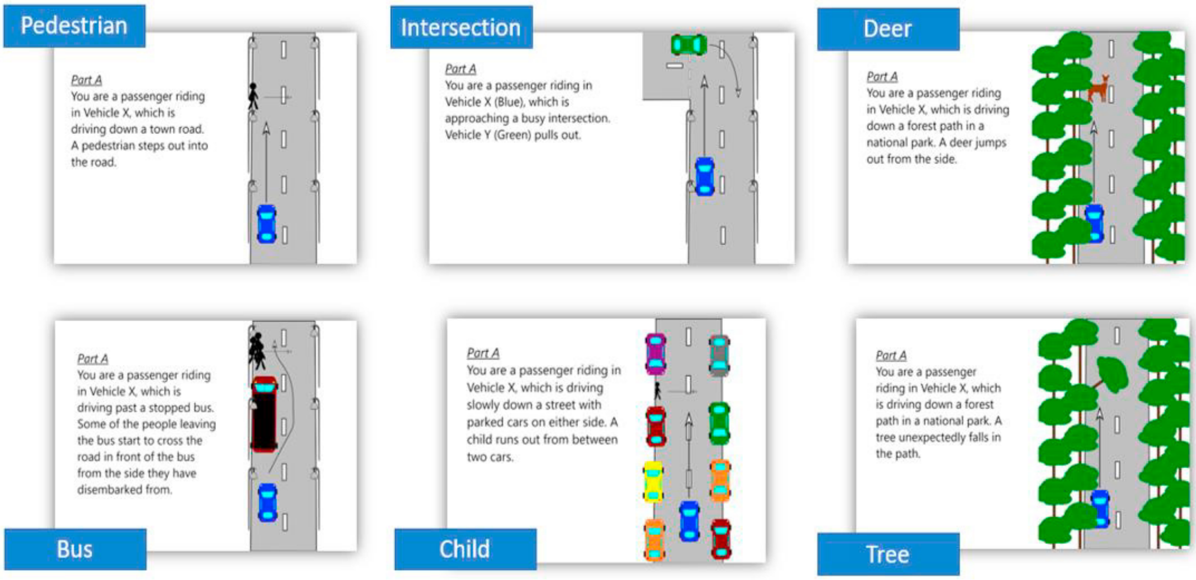

Figure 1 Part A of all six scenarios

Despite their cost-effectiveness and versatility, there are drawbacks associated with the usage of vignette stories. First, they can't capture the full details/dynamics of an accident scenario. The salience of particular aspects of the event might be artificially magnified, which will cause the effects of some variables to be exaggerated. This is particularly problematic when one attempts to apply the findings to more formal settings (e.g., accident investigations, court rooms, etc), where the details of a case undergo a high level of scrutiny. Second, some aspects of an accident sequence are very difficult to manipulate in a parametric manner with text-based stimuli (e.g., acceleration, speed, visibility, density of traffic, viewing perspective, etc.).

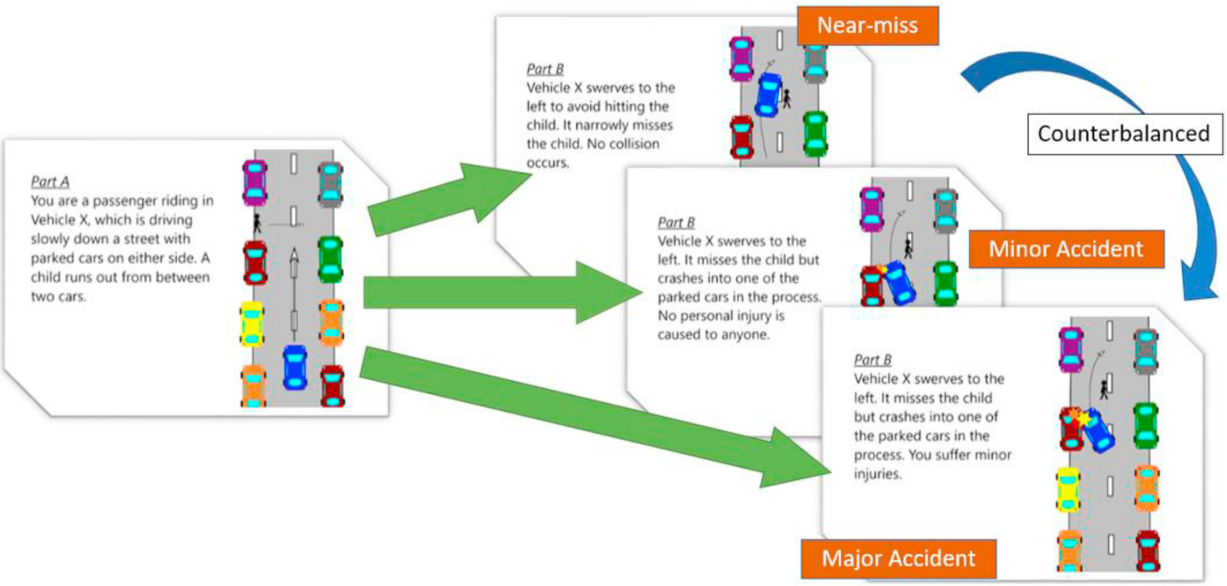

Figure 2 Part A of the "Child" scenario, paired with three alternative versions of Part B

2.2. Computer-generated Animations/VR

Animated accident sequences seem to be able to combine the best of many worlds – they have the potential of conveying more details and hence more representative of what happen, or what could happen in a real accident. They also allow a wide range of variables to be manipulated with relative ease. The experience of the accident can be made even more immersive when teamed with the strength of the VR technology. One study that adopted this type of stimuli is by Kallioinen et al [17], who used Unity to generate scenarios in VR environments to investigate preferences of moral decisions people would like autonomous vehicles to make in critical situations. The decisions were binary and typically involved steering to the left or right, which would result in different casualties (e.g., a small group of pedestrians or a large group). Participants experienced these situations by watching VR animations from different perspectives (i.e., passenger, observer, pedestrian in the smaller group and pedestrian in the larger group) – a variable that would have been very difficult to manipulate using text-based stimuli.

Another added benefit of VR is that participants can observe freely in the environment, hence removing the artificial diversion of attention. However, this could also compromise the potencies of variable manipulations because participants won't necessarily notice the change in the variable if it was subtle. Another limitation of this type of stimuli is that their fidelity is largely dependent on the capability of the software that's been used to generate the animation/VR as well as the aptitude and effort of the programmers. A poorly executed animation or VR sequence can mislead the participant, for example, by distorting how different parties would interact with each other in a real traffic incident.

2.3. Driving Simulators

Depending on the complexity and capability of the simulator – from fixed-based one-seater driving cockpit with LED screens, all the way up to real-sized driving cabins coupled with motion platforms and panoramic screens - a driving simulation might be the most realistic way for a human participant to experience a traffic incident. The virtual environments generated by the driving simulation software (e.g., STISIM, SCANeR Studios) are arguably superior than that generated by game engines (e.g., Unity) for this kind of purpose because they put more emphasis on realistic representation of the dynamics of vehicles as well as the physical interactions between objects/road users. But the shortcomings associated with this method are also evident. First, driving stimulators are expensive to buy and run. Second, it's extremely time-consuming to collect data using a driving simulator – typically only one participant can be tested at a time and a lot of preparations need to go into running each session. Finally, it's difficult to make cross-platform comparison of data because simulators are dissimilar to each other in many ways. Therefore, when a finding fails to be replicated using a different simulator, it is difficult to isolate and pinpoint the potential causes.

3. A New Approach – Simulation-software-generated Animations

In this section we present a novel method of generating animated video stimuli using driving simulation software, which we argue strikes a good balance of fidelity, versatility and cost-effectiveness. We also provide an example of one of our own studies in which we used this method to test the effect of *driving style* of autonomous systems and human drivers on post-accident attitudes, which would otherwise be very difficult to manipulate using a text-based vignette stimulus. Finally, we present some data from this study to illustrate the effectiveness of this variable manipulation.

3.1. Materials Description

In our study, the human participants responded to an online questionnaire which contained animated video clips as illustrated in Figure 3. The animations were based on the "bus scenario" presented in Section 2. The participants were asked to focus on a white family SUV as the target vehicle, which was said to be driven either by a human driver or an autonomous system. During the first half of the video (See Figure 3a), the target vehicle was shown to follow a bus on a single-carriage way in a suburban area with traffic in both directions. The manipulation of driving styles was operationalized by varying the frequency of overtake attempts and the extent of the lateral movement of the vehicle when making these attempts. In the “low lateral movement” version, the target vehicle was consistently following the bus in the front while making no attempts to overtake. In the “medium lateral movement” version, the target vehicle made tentative effort to overtake the bus by occasionally steering into the opposite lane and quickly steering back. In the “high lateral movement” version, the target vehicle displayed strong intention to overtake the bus by constantly weaving from left to right behind the bus and steering deeply into the opposite lane, only to abort the overtaking maneuver at the last second due to traffic coming from the other direction.

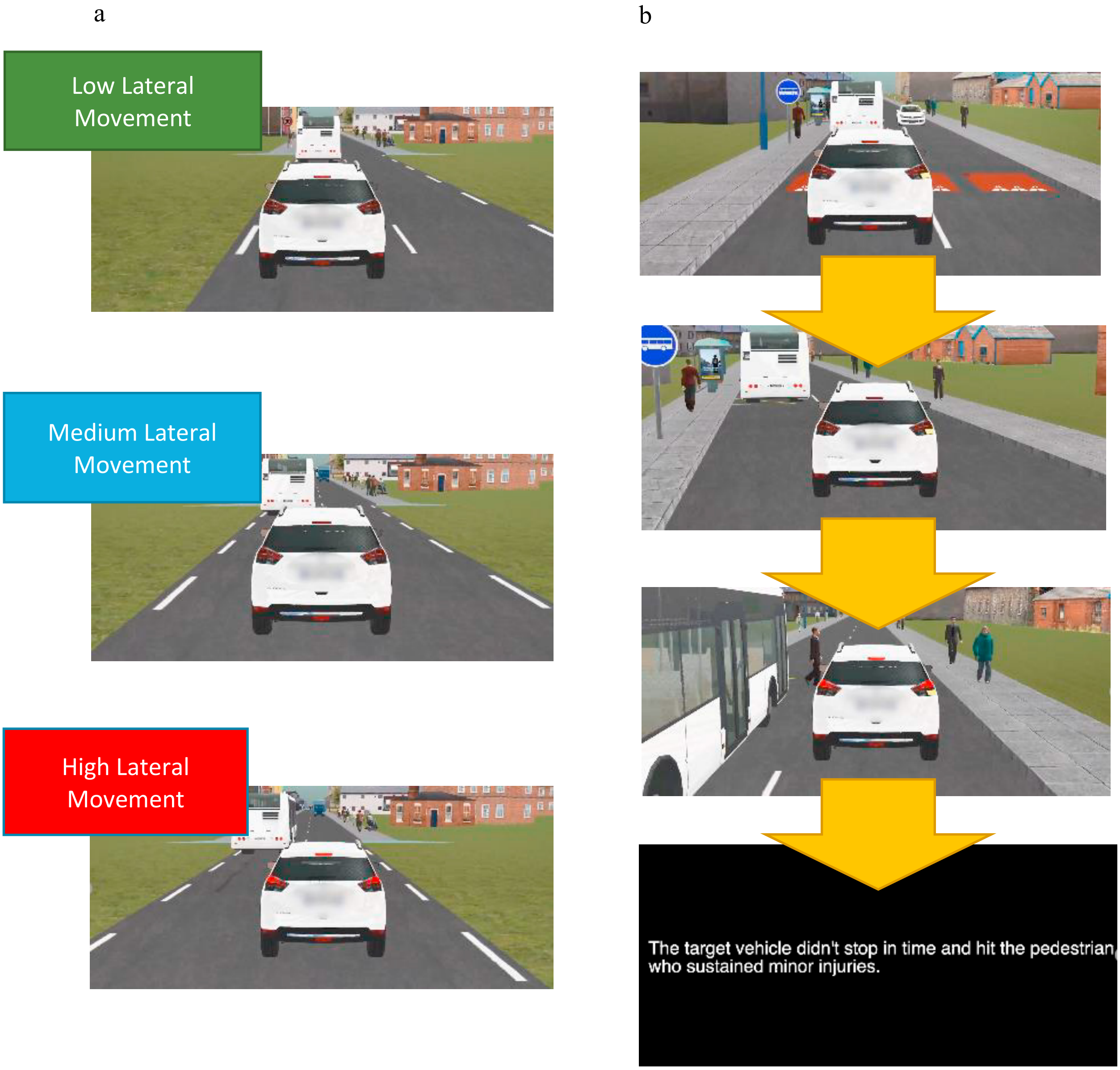

Figure 3. (a) Comparison of the three driving styles at the same temporal location in the first half of the videos; (b) Screenshots of the accident sequence featured in the second half of video. (Full videos can be accessed via https://vimeo.com/581885250; https://vimeo.com/581885298; https://vimeo.com/581885366)

In the second half of the video, the target vehicle followed the bus into a densely populated town (See Figure 3b). The bus pulled over into a bus stop. The target vehicle then indicated and started to overtake the stopped bus using the opposite lane. As the target car was about the clear the bus, a pedestrian suddenly appeared from behind the bus. The participants did not witness footage of the pedestrian being hit. Instead, the video cut to a black screen and two lines of white text appeared in the middle reading “The target vehicle didn’t stop in time and hit the pedestrian, who sustained minor injuries”. This ending was the same for all three versions.

The videos were presented to the participants using a fixed aspect ratio of 16:9. But the actual size of the video frame would depend on many factors outside the experimenters’ control (e.g., the screen size of their device, browser settings, etc.). The video had no audio output. All three versions of the video lasted about two-and-half minutes and the webpage was configured in such a way that the videos would automatically start to play as soon as the participant reached to that page and they would only play once (the page automatically jumped to the next at the end of the video). The participants couldn’t pause, rewind, fast-forward or manipulate the video in any way during the playback.

3.2. Procedures to generate the animations

The procedure with which we generated the animations was the following: 1) A script was written specifying the sequence of events that should occur in the scenario; 2) A virtual traffic environment was built using the simulation software SCANeR Studio, along with trigger mechanisms programmed into the environment for the prescribed events to take place at various temporal points (e.g., bus would pull into the bus stop when it reached a particular marker on the road; The pedestrian would start walking across the road when the target began to overtake the bus, etc.); 3) One experimenter initiated the simulation and drove the target vehicle through the virtual environment in a way that’s consistent with the written script. The driving sequence was recorded by the simulation software; 4) the recording was exported from the simulation software in MP4 format and was edited to the presented form using Final Cut; 5) All versions of the video were uploaded to a commercial online video hosting website called Vimeo in MP4 format; 7) The links for these videos were then embedded in the online questionnaire.

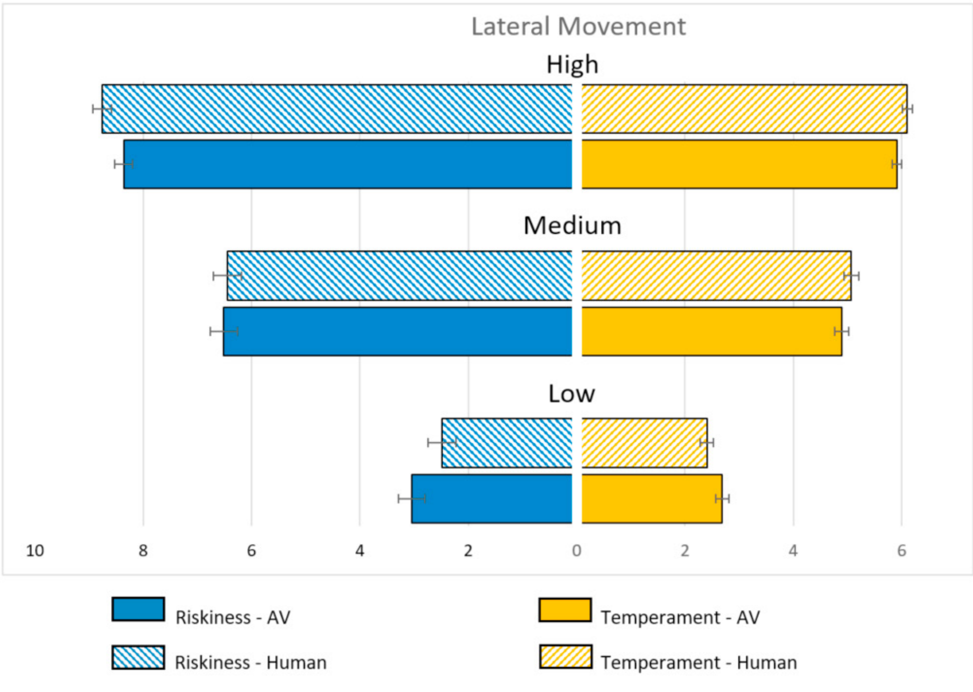

Figure 4 Mean ratings of perceived riskiness and temperament of driver for autonomous systems and human drivers across three lateral movement conditions

3.3. Effectiveness of variable manipulations

A subset of data from one of our studies is presented in Figure 4, which shows participants' mean ratings on the perceived riskiness of the behavior of the vehicle and the perceived temperament of the driver/operator across three different lateral movement conditions. The sample consisted of 177 participants which were recruited online via *Prolific*. 120 (68%) of them were females and 57 (32%) were males, with an average age of 32 (SD = 11). The perceived riskiness was measured by an 11-point scale on which the participants rated the extent to which they thought the behaviours of the vehicle was risky. A 2 (Operator: human driver, autonomous system) X 3 (Lateral movement: low, medium, high) mixed analysis of variance (ANOVA) revealed a significant main effect of lateral movement ($F(2, 350) = 451.61$, $p < .01$, $\eta^2 = .721$), characterised by an escalating trend from the low lateral movement condition to high movement condition. What's more, as the degree of lateral movement increased, participants displayed a stronger inclination to rate the behaviour of the autonomous system less risky than human drivers ($F(2, 350) = 3.02$, $p = .05$, $\eta^2 = .02$). A similar pattern was observed in the perceived temperament of the driver ($F(2, 350) = 557.47$, $p < .01$, $\eta^2 = .76$); $F(2, 350) = 3.29$, $p = .04$, $\eta^2 = .02$), which was measured by presenting the participants with six pairs of adjectives with opposite meanings (cautious-reckless, patient-anxious, peaceful-angry, calm-nervous, carefree-worried, submissive-aggressive) and asking them to rate each pair on a 7-point bipolar scale. These results provide evidence that the manipulation of vehicle lateral movement was effective using the simulator-generated animation as experimental stimuli.

4. Discussion

Compared to other methods, using driving simulation software to generate animations has several advantages. First, it has high fidelity/realism. It captures more details of accident sequences than vignette stories and offer a more realistic representation of the vehicle dynamics than animations generated by game engines. Second, it's easy to control and manipulate variables parametrically. A lot of the built-in function of driving simulation software already allows many parameters of the vehicle as well as the traffic environment to be adjusted/specified. Aspects like engine power output, suspension characteristics, speed, weather, visibility, density of traffic, road conditions can be easily manipulated. More so than game engines with which one needs to "reinvent the wheel". The data presented in this paper also attests to the effectiveness of variable manipulations using the proposed method. In our study, varying the degree of the vehicle lateral movements had a potent effect on perceived driving characteristics – a finding that is comparable to previous studies which conducted real-life road trials to test the effect of driving style of AVs [23]–[25]. Third, it's cost-effective since materials and mechanisms that are needed to construct a virtual driving scenarios are usually immediately available and can be "taken off the shelf". The videos can also be embedded in online questionnaires and disseminated widely around the world. This allows data collection on a bigger scale than simulation studies and the possibility of acquiring a more representative sample. This is particularly valuable for research projects which have elements of cross-country comparisons like ours.

However, it is not to say that this method is a superior option under all circumstances. First, the upfront cost of generating such stimuli is still high - one still needs to acquire driving simulation software (and possibly hardware) to make this possible – and those of the highest quality are expensive. Thus, for small-scale projects, game engines like Unity offer more flexibility and cost-effectiveness, if one is adept at the programing and/or can hire someone who can code in Unity. Second, for research where detailed representation is not necessary (e.g., research on moral judgments), vignette studies still offer the best cost-benefit ratio. Animation-based stimuli are still cumbersome compared to short vignette stories and hence only a limited number of scenarios can be presented. This limits the diversity of the situations featured in the experiment as well as the representativeness of findings. Third, simulator-based lab testing still offers the highest level of realism and immersion of scenarios. It also allows interactions between the human participant and the vehicle interfaces.

5. Conclusions

In the emerging research field of autonomous vehicles accidents, it is paramount to develop high-fidelity experimental stimuli to represent accident scenarios in a realistic way. A number of factors need to be considered before choosing the format of accident representations. While vignette stories, computer-generated animations/VR and driving simulations all have their advantages, the method introduced in this paper strikes a good balance of fidelity, versatility and cost-effectiveness and is best suited for research where a high level of details of the accident need to be presented to the human participants and the data needs to be collected in a larger scale.

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