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What driving style makes pedestrians think a passing vehicle is driving automatically?

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ABSTRACT

An important question in the development of automated vehicles (AVs) is which driving style AVs should adopt and how other road users perceive them. The current study aimed to determine which AV behaviours contribute to pedestrians' judgements as to whether the vehicle is driving manually or automatically as well as judgements of likeability. We tested five target trajectories of an AV in curves: playback manual driving, two stereotypical automated driving conditions (road centre tendency, lane centre tendency), and two stereotypical manual driving conditions, which slowed down for curves and cut curves. In addition, four braking patterns for approaching a zebra crossing were tested: manual braking, stereotypical automated driving (fixed deceleration), and two variations of stereotypical manual driving (sudden stop, crawling forward). The AV was observed by 24 participants standing on the curb of the road in groups. After each passing of the AV, participants rated whether the car was driven manually or automatically, and the degree to which they liked the AV's behaviour. Results showed that the playback manual trajectory was considered more manual than the other trajectory conditions. The stereotype automated 'road centre tendency' and 'lane centre tendency' trajectories received similar likeability ratings as the playback manual driving. An analysis of written comments showed that curve cutting was a reason to believe the car is driving manually, whereas driving at a constant speed or in the centre was associated with automated driving. The sudden stop was the least likeable way to decelerate, but there was no consensus on whether this behaviour was manual or automated. It is concluded that AVs do not have to drive like a human in order to be liked.

1. Introduction

Each day more than 3400 people die in traffic worldwide (World Health Organization, 2018), with half of the victims being vulnerable road users (WHO, 2018). An estimated 94% of road traffic crashes are caused by human error (National Highway Traffic Safety Administration, 2015). Automated vehicles (AVs) have the potential to increase road safety, as they can react faster than human drivers and are not subject to human errors, such as lapses of attention.

An important question in the development of AVs is which driving style these vehicles should use, and how pedestrians would judge these driving styles (Ackermann et al., 2019; Ekman et al., 2019; Fuest et al., 2018). Should the AV drive stereotypically, that is, drive in the middle of the roadway, brake with perfectly constant deceleration, always stick to the traffic rules, and come to a halt exactly at a stop line, or should it be programmed to drive like a manually-controlled vehicle, including imperfections in the control of the vehicle?

It is tempting to assume that an AV should drive as 'perfectly' as possible. However, a potential problem is that such driving behaviour may not match what other road users are used to. Some prototypes of AVs are known for being hit from behind and holding up traffic because of strict adherence to rules (Stewart, 2018; Vinkhuyzen and Cefkin, 2016). A related concern is that stereotypical automated driving may cause misuse. There is a large body of literature showing that people tend to overtrust automation that appears to perform infallibly (e.g., Parasuraman and Riley, 1997). Pedestrians and cyclists may recognise that a vehicle is driving automatically, and may misuse this information, for example, by crossing the road with impunity, as pointed out by Millard-Ball (2018).

It has been hypothesised that the acceptance of the AV will increase if

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the AV drives in a stereotypical human manner (Hecker et al., 2019; Sun et al., 2020). If these ideas are extended further, one could think of AVs that behave in a manner that is indistinguishable from manual driving for a passenger or outsider. In this case, the AV passes what can be termed the 'Turing test of automated driving' (Emuna et al., 2020; Li et al., 2018; Stanton et al., 2020; cf. Turing, 1950).

A variety of studies have proposed algorithms for letting an AV drive in a human-like manner. These algorithms concern human-like decision-making at intersections (De Beaucorps et al., 2017), human-like car following (Fu et al., 2019), driving trajectories based on estimated human behaviour or perceived risk (Guo et al., 2018; Kolekar et al., 2020; Kraus et al., 2010; Shin et al., 2018; Wang et al., 2020; Xu et al., 2020), and human-like braking behaviour (Lehsing et al., 2019). In current traffic, drivers might stop close to the stop line to indicate their priority, or conversely, far before the stop line to indicate to pedestrians that they can cross (Risto et al., 2017). The former has been recognized by developers of AVs: the latest prototypes from Waymo have been said to be capable of human-like 'crawling forward' at pedestrian crossings (Niedermeyer, 2019), whereas a study involving Jaguar Land Rover tested an AV that exhibited human-like 'peeking' when approaching road junctions, as if it was looking before proceeding (Oliveira et al., 2019). More generally, many types of driving simulators, including computer games used for entertainment purposes and simulators used for scientific research, employ computer-controlled traffic that emulates manual driving (e.g., Al-Shihabi and Mourant, 2003; Muñoz et al., 2013).

Elbanhawi et al. (2015) recommended more human factors studies for validating behavioural models and planning algorithms of AVs. So far, several studies have examined how humans respond to AVs that have been programmed to perform in a human-like manner. In a driving simulator experiment by Rossner and Bullinger (2019), 30 participants assuming the role of a passenger of an AV encountered oncoming traffic. In one condition, the AV kept the centre of the lane, whereas, in a second condition, the AV moved to the right edge of the lane when encountering oncoming traffic, as a human driver might typically do. Results showed that the latter condition led to higher perceived safety than the former. Additionally, driving simulator research by Griesche et al. (2016) showed that drivers prefer to use an AV that drives in a way that resembles their own driving style as compared to other manual driving styles. Further evaluations into the driving styles of AVs have been performed by Hartwich et al. (2018), Oliveira et al. (2019), and Sun et al. (2020).

Most human factors studies on human-like AVs have focused on the passenger inside the AV, whereas only a few studies have taken the pedestrian's point of view. An exception is a Wizard-of-Oz study by Fuest et al. (2018b), which found that human-like driving behaviours, such as increasing the vehicle's lateral distance from the pedestrian, can communicate the vehicle's intention to pedestrians. Furthermore, with exceptions (Fuest et al., 2018; Oliveira et al., 2019), studies on human-like AVs have been conducted in simulators. It can be argued that simulators do not offer the true-to-life experiences required for measuring the human acceptance of AVs. Regarding pedestrians outside of the AV, the perception of an approaching AV's behaviour may depend on subtleties such as the vehicle's pitch angle and the perception of vehicle speed, which may not come across veridically in a virtual environment.

1.1. Study aim

In this study, the viewpoint of pedestrians outside of the AV was taken. The aim was to investigate what behaviour of an AV gives an outside observer the impression that the vehicle is being driven automatically instead of manually. To this end, we investigated the effect of different stereotypical manual and automated curve-driving and braking behaviours on ratings of automaticity and likeability. The AV prototype was programmed to follow a curvy section of the testing centre. Equivalently, the braking behaviour of the AV prototype was tested at a pedestrian crossing scenario.

2. Method

2.1. Participants

In total, 24 employees and interns of Nissan participated in the experiment. The experiment took place during three sessions, with 10, 5, and 9 participants present per session, respectively. The uneven distribution of the participants is attributable to the availability of the recruited people. Of the 24 participants, 20 were male, and 4 were female. The mean age was 35.5 years (SD = 9.6). Table 1 provides an overview of the answers to the questions on the primary mode of transportation, as well as monthly frequency and mileage of driving.

2.2. Road and automated vehicle

The experiment took place at a testing site of Nissan in Kanagawa, Japan. The AV was a prototype based on the second-generation Nissan Leaf, a small electric car. The road consisted of two segments: a curvy part of 5.6 m in width and 180 m in length with seven corners and no lane markings, and a two-lane straight segment of 6.85 m in width and 100 m in length with a zebra crossing at the end. The experiment was divided into two parts: (1) the 'trajectory' part: the AV following trajectory profiles on the curvy segment of the road, and (2) the 'deceleration' part: the AV adhering to deceleration profiles at the straight segment. The trajectory and deceleration parts had different start and end locations. The curvy part of the road is normally used as a two-way road, and all participants were aware of that.

2.3. Participants' location

During each part of the experiment, the participants stood in a group formation, allowing a clear view of the road. The participants' location for the trajectory trials was at the fourth corner of the curvy section. The participants' location for the deceleration trials was at the zebra crossing at the end of the straight road segment, where the vehicle decelerated to a full stop; see Fig. 1 for the overview of the location, driven segments,

Table 1
Answers to driving experience questionnaire items.

Question	1	2	3	4	5	6	7	Options
Primary mode of transportation	10	11	0	3	0			1 = Private vehicle; 2 = Public transport; 3 = Motorcycle; 4 = Walking/Cycling; 5 = Other
How often did you drive a vehicle in the last 12 months?	6	2	11	2	1	2	0	1 = Every day; 2 = 4–6 days a week; 3 = 1–3 days a week; 4 = Once a month to once a week; 5 = Less than once a month; 6 = Never; 7 = I prefer not to respond
How many km did you drive in the last 12 months?	2	2	8	9	2	0	1	1 = 0 km; 2 = 1–1000; 3 = 1001–5000; 4 = 5001–15000; 5 = 15001–20000; 6 = 20001–25000; 7 = 25001–35000; 8 = 35001–50000; 9 = 50001–100000; 10 = More than 100000; 11 = I prefer not to respond

Note: No participants chose options 8–11 for the question '*How many km did you drive in the last 12 months?*'

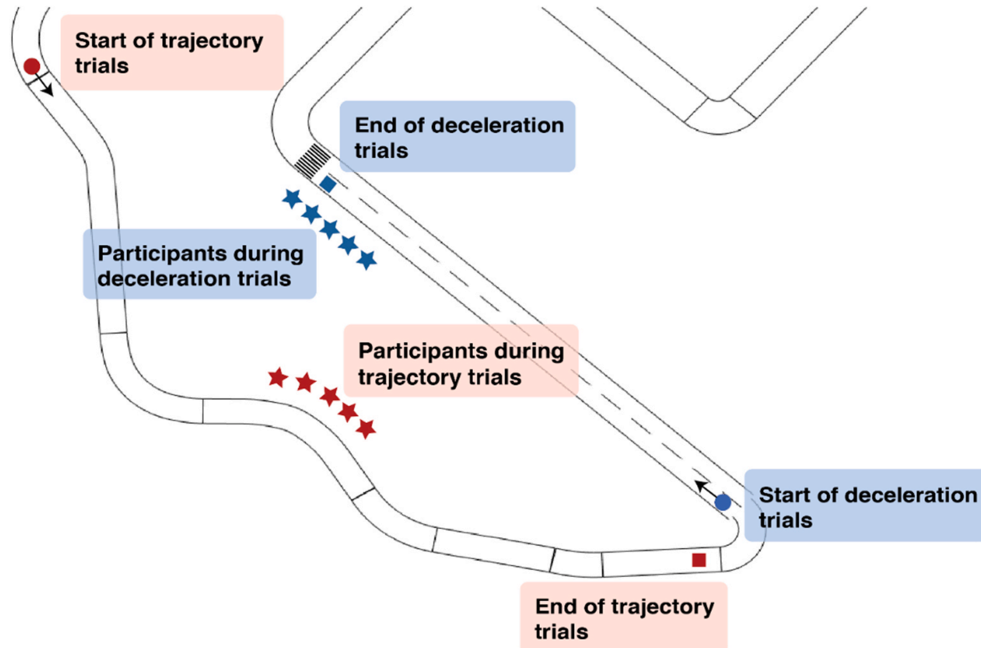

Fig. 1. Start and end locations of the vehicle and locations of the participants during trajectory (blue) and deceleration (red) trials. No lane marking was present for the trajectory part. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and locations of the participants.

2.4. Experimenters

An experimenter was standing behind the participants to give instructions in English and Japanese before each part of the experiment. Furthermore, a safety driver sat behind the wheel of the car during both parts of the experiment. During all trials, the safety driver kept his hands on the lower half of the steering wheel so that the hands were not visible from the outside. He was tasked to maintain the same posture and facial expression during all trials. The safety driver during Sessions 1 and 3 was different from the safety driver in Session 2. Both drivers received the same instructions. An experimenter was sitting in the back seat of the car to control data logging and load profiles between trials. The experimenter in the car and the experimenter at the participants' location used a walkie-talkie to coordinate actions when a new trial was starting.

2.5. Procedure

Each session lasted about an hour. First, the participants signed an informed consent form. Before the first trial in the session, the participants were given instructions. The instructions and all text in other forms were presented in both English and Japanese. The aim of the experiment in English was stated as '*to determine whether the way an automated car is driving makes the car seem more machine-like or human-like*'. Participants were also instructed that '*There are other participants in the study standing next to you. They have the same role as you. During the experiment, please, do not talk with other participants next to you. Do not look at their answers to the questions*'. The sheet with instructions also included an introductory questionnaire (Table 1). The answers were provided in handwritten form.

The participants were not informed about whether the car was driving automatically or manually in any trials. Each part of the experiment also contained specific instructions. Instructions for the trajectory profiles part were '*You are standing at the side of the road. Then, you notice a car that is approaching. Observe the way the car is taking corners on the curvy section in front of you. Feel free to move your body, but do not change your location. After each trial, answer the questions for that trial. In this part of the experiment, you will participate in 10 trials. After the last trial, you will have a short break. Please turn the sheet and wait for the start of the first trial*'.

Instructions for the deceleration profiles part were '*You are standing at the side of the road in front of a zebra crossing. You wish to cross the road. Then, you notice a car that is approaching. Observe the way the car is decelerating. Feel free to move your body, but do not change your location. Do not cross the road or change your location after the car has stopped. In this part of the experiment, you will participate in 8 trials. After each trial, answer the questions for that trial. Please turn the sheet and wait for the start of the first trial.*'

After the last trial of the first part of the experiment, the participants were asked to move to the location of the second part of the experiment at the pedestrian crossing. They were reminded not to interact with each other and not look at the sheets with questionnaires in the hands of other people.

Each condition had two trials. The order of the trials in each part (10 trials in the 'trajectory' part, and 8 trials in the 'deceleration' part) was randomised. Table 2 shows the timeline of the experiment.

2.6. Behaviour of the automated vehicle – Trajectory part

As mentioned, the experiment consisted of two parts, each part comprising a number of conditions in which the AV drove in a highly repeatable manner with a specific driving style. The conditions were: playback manual driving (acting as a baseline condition), stereotypical automated driving (featuring behaviours that may be regarded as typically belonging to an AV), and stereotypical manual driving (featuring behaviours that only humans are expected to show). All conditions were piloted to ensure that the vehicle behaved as intended (e.g., stopping at the stop line).

In the first part of the experiment, five trajectory profiles were executed. For each trial, the car started and ended behind buildings, so that the participants could not observe the car outside of the curvy section of the track. All trajectory profiles were pre-programmed and played back during the experiment.

Table 2
Timeline of the experiment for each of the three sessions.

	Part	Condition	Trials	Time
		Instructions and introductory questionnaire		10 min
1	Trajectory	Playback manual driving	2	3 x 2 min
2	Trajectory	Stereotype automated 'road centre tendency'	2	3 x 2 min
3	Trajectory	Stereotype automated 'lane centre tendency'	2	3 x 2 min
4	Trajectory	Stereotype manual 'normal'	2	3 x 2 min
5	Trajectory	Stereotype manual 'safe'	2	3 x 2 min
		Break		5 min
1	Deceleration	Manual braking	2	2 x 2 min
2	Deceleration	Stereotype automated 'fixed deceleration'	2	2 x 2 min
3	Deceleration	Stereotype manual 'sudden stop'	2	2 x 2 min
4	Deceleration	Stereotype manual 'crawling forward'	2	2 x 2 min
		Total:	18	61 min

- Playback manual driving. This trajectory was created before the experiment by recording a manual drive of the safety driver (see Fig. A1 in Appendix). The speed was held approximately constant at a mean speed of 17.8 km/h.
- The stereotype automated trajectory 'road centre tendency' refers to a condition where the AV was inclined to steer towards the middle of the road, as can be seen in Fig. A2. It tended to cut curves but drove close to the centre of the road on the straight segments. Again, the speed was held constant near 17.8 km/h.
- The stereotype automated trajectory 'lane centre tendency' refers to a condition where the AV's controller was inclined to steer towards a certain lateral distance (0.75 m) from the lane centre (see Fig. A3). Even though there were no road markings, the track segment was wide enough to contain two lanes. The 'lane centre tendency' condition represents how AVs of the future may drive, but it was regarded by the experimenters during the design stage as more human than the 'road centre tendency' condition. The speed was held constant near 17.8 km/h.
- The stereotype manual 'normal' trajectory refers to an AV that demonstrated strong curve cutting as well as slowing down for curves and accelerating out of curves. The corresponding trajectory and speed are shown in Fig. A4. Curve cutting can be recognized from the large lateral positions of about 1.6 m. The mean speed was 17.9 km/h.
- The stereotype manual 'safe' trajectory resembled the stereotype manual 'normal' trajectory, except that the former drove at a lower mean speed of 17.0 km/h setting (see Fig. A5).

2.7. *Behaviour of the automated vehicle – Deceleration part*

During the second part of the experiment, four deceleration profiles were executed. The starting location was behind a building, and the participants were unable to see the car entering the last corner before the straight segment of the track.

- The manual braking profile was initially planned to be pre-recorded and played back. However, the control logic of the vehicle did not allow a precise playback, and the profile was executed by the safety driver manually performing the deceleration from ~27 km/h to 0 km/h, starting from 30 m before the point of stopping at the zebra crossing with a 'natural braking pattern' (see Fig. A6). The location of the start of the deceleration aligned with a permanently placed pole on the side of the road, which served as a marker to the driver. The deceleration of the vehicle was about 0.9 m/s^2.
- For the stereotype automated 'fixed deceleration' profile, the AV decelerated from ~27 km/h to 0 km/h, starting from 40 m from the zebra crossing. The deceleration as a function of travelled distance was constant (see Fig. A7). This deceleration corresponded to an initial peak deceleration of 1.0 m/s^2. The car stopped a little over the stop line, with its front wheel at the stop line.
- For the stereotype manual 'sudden stop' deceleration profile, the AV performed an abrupt deceleration from ~27 km/h to 0 with the deceleration of 0.25 g starting from 15 m before the point of stopping at the zebra crossing (see Fig. A8 in Appendix). The AV decelerated with about 2.0 m/s^2.
- The stereotype manual 'crawling forward' deceleration profile was intended to mimic human deceleration, where a human driver underestimates the distance needed to come to a full stop, and after realising that the car would stop too soon, applies a lower rate of deceleration (see Fig. A9). For this profile, the AV performed a fixed deceleration (as a function of travelled distance) from ~27 km/h to 7 km/h with a peak deceleration of about 1.0 m/s^2, followed by a deceleration of about 0.2 m/s^2. The car stopped a little over the stop line, with its front wheel at the stop line.

As mentioned, the manual braking profile (Fig. A6) featured manually controlled braking to a full stop. The profiles for the 'fixed deceleration', 'sudden stop', and 'crawling forward' conditions were preprogrammed and played back during the experiment. Fig. A1-A5 (trajectory trials) and A7–A9 (deceleration trials) illustrate that the six repetitions of the different trials were repeated with high accuracy.

2.8. *Questionnaires*

After participants had become familiar with the instructions for the trajectory profiles, they received a sheet with questions. The questions were the same for all trials in both parts of the experiment. Three items needed to be answered (the text in English is reported below):

1. *'How automated was the way the car drove in this trial? Answer on a scale of 1 to 5, with 1 being manual driving and 5 being automated driving'*. For the purpose of analyses, the coding was reversed so that 1 corresponded to automated driving and 5 to manual driving.
2. *'Explain your answer. What made you think that the car was driving manually or automated?'* The answer had to be given in either English or Japanese.
3. *'Please rate your impression of the vehicle on these scales'*. The answer had to be given for five items: Machine-like/Human-like, Mechanical/Organic, Dislike/Like, Unintelligent/Intelligent, and Anxious/Relaxed, with response options 1–5. These five items were taken from Bartneck et al. (2009). More specifically, in their widely cited paper, Bartneck et al. (2009) present a series of questions (in English and Japanese) that can be used to judge users' perception of robots. Because an AV is in essence a robot, these questionnaires appeared to be highly suitable for our purpose. We selected one item from each of their five questionnaire dimensions (anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety, respectively).

The supplementary material contains all instructions and questionnaires given to the participants.

Figs. A1-A9 in the Appendix show the driven trajectory and speed for each trajectory and deceleration condition. During the first session, the first trial of the manual braking profile was performed incorrectly, and it therefore was repeated at the end of the session. It can be seen that in the stereotype automated 'road centre tendency' condition, the AV cut curves and drove fairly close to the road centre on straights (see Fig. A2). Similarly, for the stereotype automated 'lane centre tendency' condition, the AV cut curves. On straights, the AV tended to move towards a lateral position of about 1.4 m (road width/4), as shown in Fig. A3.

2.9. Statistical analyses

In cases where the answer of the participant could not be interpreted from the hand-drawn markings, a value between possible answers was used (e.g., 1.5 would be assigned if both options 1 and 2 were encircled). The means and standard errors (i.e., standard deviation divided by the square root of the sample size, $n = 24$) of the responses to the six questionnaire items are presented in bar graphs.

For each of the six questionnaire items, pairwise comparisons were made between the conditions using paired-samples *t*-tests. De Winter and Dodou (2010) showed through computer simulation that independent-samples *t*-tests can safely be used (as judged from Type I and Type II error rates) on five-point Likert items. The reason is that outliers, which could undermine the power of the *t*-test, cannot be present on five-point scales. By extension, the paired-samples *t*-test, which operates on differences between scores, should be safe to use as well.

p-values smaller than 0.01 were regarded as statistically significant. A relatively conservative alpha value was chosen to limit the probability of false positives, considering that multiple paired comparisons were performed between the experimental conditions.

3. Results

Figs. 2 and 3 show the means, standard deviations, and results of the paired-samples *t*-tests for the six questionnaire items, for the trajectory and deceleration trials, respectively. The supplementary material contains the full results, including test statistics, Cohen's *d*, and the within-subjects variant of Cohen's *d*: Cohen's d_z. This information is complementary to the information in Figs. 2 and 3.

In Fig. 2, it can be seen that the playback manual condition was regarded as the most manual and that none of the four other conditions resembled manual driving closely. The stereotype manual 'safe' condition was regarded as relatively mechanical, disliked, unintelligent, and anxious. The stereotype automated condition 'lane centre tendency' was significantly better liked and regarded as more relaxed than the two stereotype human conditions.

Fig. 3 shows that the stereotype automated 'sudden stop' was generally disliked and regarded as unintelligent and anxious. There were no significant differences between the other conditions, except that the manual braking was better liked than the stereotype manual 'crawling forward' condition.

The correlation matrix between questionnaire items (see Table 3) shows that likeability (Q4) strongly correlated with perceived intelligence (Q5) ($r = 0.91$, $n = 24$), but likeability and perceived intelligence hardly correlated with ratings of the extent to which the vehicle was driving automatically or manually (Q1) ($r < 0.2$, $n = 24$).

For the five-point question '*How automated was the way the car drove in this trial?*', participants had to explain what made them think the car was driving automatically or manually. Four participants wrote their answers to the open-text questions in English, and the other 20 participants wrote in Japanese. The answers in Japanese were translated into English by a native speaker of Japanese. Table 4 summarises the comments for each profile. A distinction is made between responses where the participant thought the car was driven manually (score 4 or 5 on the question '*How automated was the way the car drove in this trial?*') and responses where the participant thought the car was driven automatically (score 1 or 2 on the question '*How automated was the way the car drove in this trial?*'). The number in each cell represents the total number of responses out of a maximum of 48 (24 participants x 2 trials per condition).

The short narrative within each cell of Table 4 represents an interpretation of the patterns identified within the comments, as judged by the first and third author of this work, together with a third person from the TU Delft. The approach used resembled that of thematic analysis (Braun and Clarke, 2006), where the researchers first familiarised

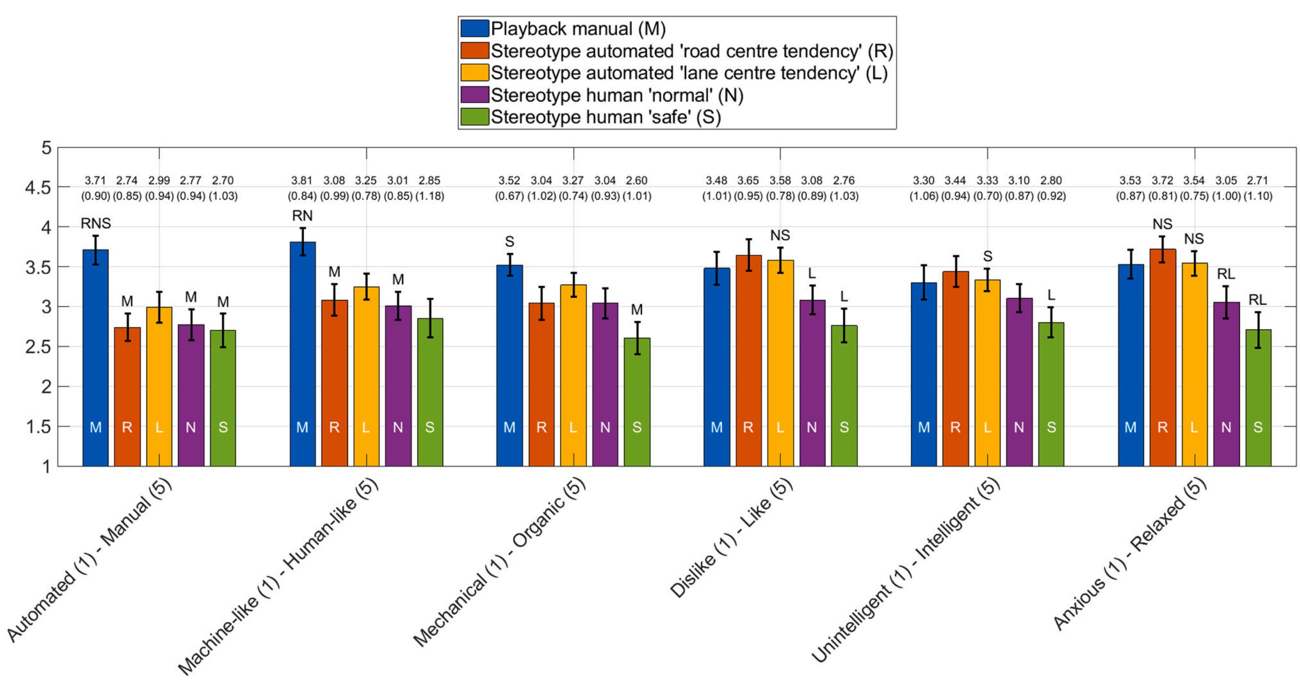

Fig. 2. Mean scores on the questionnaire for the five trajectory conditions. The letters above each bar indicate which conditions are statistically significantly different from each other ($p < 0.01$). The meaning of the letter codes is indicated in the figure legend. For example, 'RNS' above the first bar means that the R, N, and S conditions differed significantly from the M condition. The error bars run from the mean ± 1 standard error of the mean. The means with standard deviations in parentheses are depicted numerically above each bar.

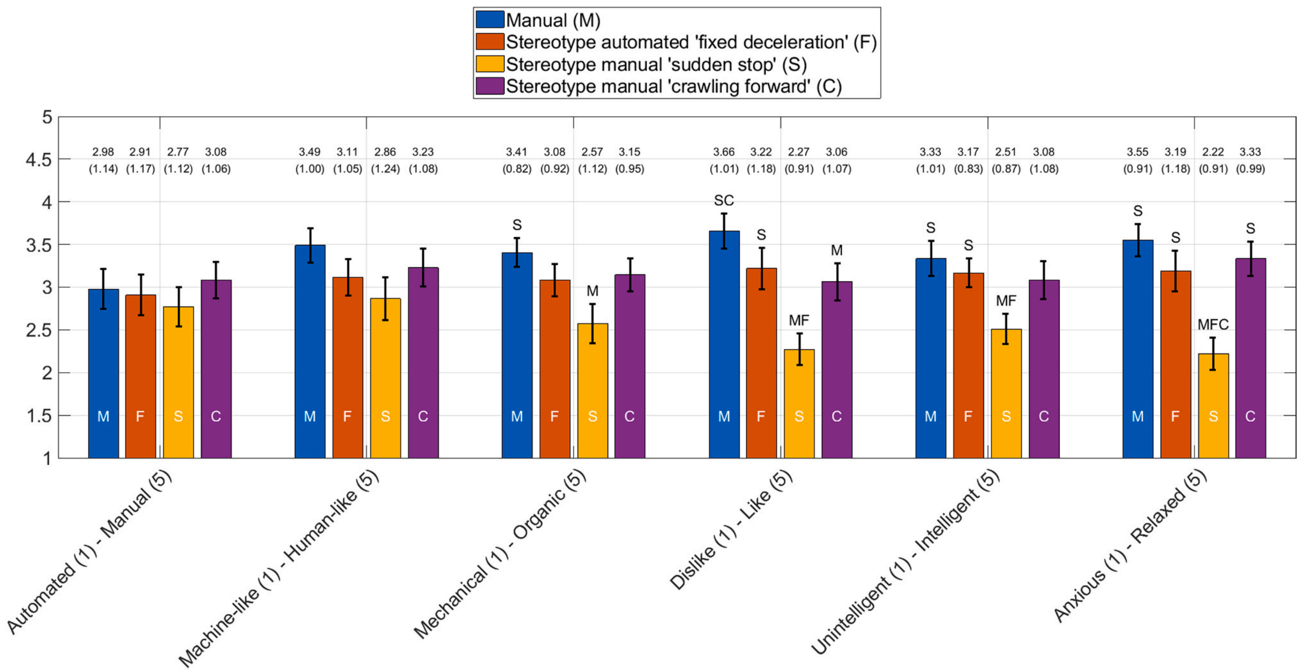

Fig. 3. Mean scores on the questionnaire for the four deceleration conditions. The letters above each bar indicate which conditions are statistically significantly different from each other ($p < 0.01$). The meaning of the letter codes is indicated in the figure legend. For example, the 'S' above the last bar means that the S condition differed significantly from the C condition. The error bars run from the mean ± 1 standard error of the mean. The means with standard deviations in parentheses are depicted numerically above each bar.

Table 3
Pearson's product-moment correlation matrix for all participants' responses (n = 24; all 9 trajectory trials and deceleration trials averaged).

	Q1	Q2	Q3	Q4	Q5	Q6
Q1. Automated (1) – Manual (5)	1.00					
Q2. Machine-like (1) – Human-like (5)	0.60	1.00				
Q3. Mechanical (1) – Organic (5)	0.53	0.67	1.00			
Q4. Dislike (1) – Like (5)	0.18	0.21	0.36	1.00		
Q5. Unintelligent (1) – Intelligent (5)	0.08	0.12	0.36	0.91	1.00	
Q6. Anxious (1) – Relaxed (5)	0.13	0.12	0.36	0.91	0.85	1.00

themselves with the data, generated codes, and searched for themes, and engaged in discussion and interpretation. The supplementary material offers each of the comments and their annotations. Table 4 offers a number of illustrative comments.

4. Discussion

What type of driving behaviour causes an AV to be considered automated and likeable? In this article, we attempted to give answers to this question through a test-track study involving different automated driving styles. Twenty-four participants were asked to stand on the side of the road and observe the AV drive with five trajectory profiles and four deceleration profiles.

The playback manual trajectory was considered the most manual trajectory profile. Based on participants' written comments, manual driving was inferred from specific behaviours, such as keeping a safe distance from pedestrians standing next to the road, an anticipatory or out-in-out driving line through curves, imperfect control when approaching a stop line, as well as specific errors that are unlikely to be made by a computer, such as exceeding the stop line. These behaviours can be related to literature about what driving behaviours may be regarded as typically human. For example, an early study by Thompson et al. (1985) pointed out that drivers should keep a larger distance from the curb when pedestrians are standing on that curb, whereas Donges (1978) found that anticipation is a crucial component of human lane keeping, where anticipation is defined as turning the steering wheel before entering the curve. Elsewhere, Barendswaard et al. (2019) indicated that curve-cutting is a typical human driving behaviour.

The AV that ran in the middle of the lane was considered likeable and smooth. This finding indicates that human-like driving is not a goal in itself, and suggests that perhaps a mechanistic driving style (i.e., driving in the middle) is what should be strived for. This remark can be related to research in human-robot interaction, where it has been debated "whether we want systems eventually to behave like humans, or whether systems should, even when much more developed, still adhere to rules that are different from the rules governing interpersonal communication" (Meyer et al., 2016).

The participants recognized some aspects of the stereotype manual conditions as corresponding to manual driving, particularly its tendency to cut corners from the outside to the inside. Overall, however, the stereotype manual conditions were considered to be automated rather than manually controlled. Possible reasons are the somewhat delayed steering response, the short distance to the curbs, and unnecessary braking actions.

As for the deceleration profiles, the stereotype manual 'sudden stop' was seen as the least pleasant and least intelligent way to brake when approaching a pedestrian crossing. However, participants were divided on whether this behaviour should be considered manual or automated. Some people thought this behaviour was characteristic of a rushed human driver, or a human driver who brakes hard for an imaginary pedestrian. Others thought that the late braking behaviour was characteristic of an unintelligent automated car that recognizes objects only late and therefore brakes at a late moment. The same dichotomy applies to other stop profiles. For example, the stereotype manual 'crawling forward' deceleration pattern was regarded as the result of poor human driving, but also as an advanced type of automation.

From the above, we conclude that participants can attribute a given vehicle behaviour to a human as well as to a machine. We hypothesise that the judgement of whether a car is driven automatically is arrived at

Table 4
Qualitative summary of responses to the question *'Explain your answer. What made you think that the car was driving manually or automated?'*. The sample size *n* refers to the number of times the participants reported a score <3 or >3 on the five-point scale for the corresponding question (*'How automated was the way the car drove in this trial?'*).

Type	Condition	Why was it regarded automated? (score 1 or 2)	Why was it regarded manual? (score 4 or 5)
Trajectory	Playback manual driving	$n = 9$ Participants reasoned that the car was automated because it drove at a constant speed (which was a correct observation). *"Trajectory was like centre (road). Speed was good, but there was no visible speed variation for curves"*	$n = 32$ Participants commented on the human-like out-in-out line through curves. Furthermore, they noted that the car kept a safe distance from the pedestrians (participants). Many participants made other remarks about the human-like line or lateral position of the car. *"Smoothly exited … in anticipation of the curve ahead"*
Trajectory	Stereotype automated 'road centre tendency'	$n = 25$ The majority of participants recognized that the car was driving in the centre of the road. Furthermore, some participants argued that the car was automated because it drove at a constant speed (which was a correct observation). *"It was driving … centre of road. Humans cut curves"*	$n = 14$ Participants noted that the car kept a safe distance from the pedestrians (participants). They also noted that the car drove in the centre, or made other remarks about the line or lateral position. *"It drove on right side. AD won't drive like that (it's against the traffic rule)"*
Trajectory	Stereotype automated 'lane centre tendency'	$n = 19$ Participants noted that the car was driving in the centre, and in a smooth/stable manner. *"The car was running slowly in the center. It seemed AD-like"* *"I thought it would be better to go to the right if there were people"*	$n = 18$ Participants noted that the car was driving smoothly and in a stable manner. They also made various other remarks about the line and lateral position. *"I felt a smooth movement. More human-like"* *"Running near the inside of the road"*
Trajectory	Stereotype manual 'normal'	$n = 21$ Participants noted that the car exhibited a somewhat unusual driving line. The steering response appeared to be delayed, and the car sometimes drove close to the road edge. *"It was smooth but the return of the steer was delayed"*	$n = 12$ Most participants commented on the human-like out-in-out line through curves. *"Approached inside at the corner …"*
Trajectory	Stereotype manual 'safe'	$n = 25$ Participants noted that the car exhibited a somewhat unusual driving line. The steering response appeared to be delayed, and the car sometimes drove close to the road edge. Furthermore, participants made remarks about the car's unusual braking behaviour (e.g., it tended to brake/reduce speed in the middle of a curve). *"… I had the impression that it was turning after the curve was recognized"*	$n = 15$ Participants commented on the human-like out-in-out line through curves. Furthermore, participants made remarks about the car's unusual braking behaviour (e.g., it tended to brake/reduce speed in the middle of a curve). *"It braked on middle of the curb. It was not AD-like because the trajectory was out-in-ou"*
Deceleration	Manual braking	$n = 21$ Some participants noted that the vehicle was braking evenly and smoothly. Otherwise, the comments were diverse. *"Smooth and moderate deceleration"*	$n = 19$ Some participants correctly recognized some unevenness in the deceleration pattern, as if a human was in control. Various other participants made unspecific remarks about the naturalness/humanness of the vehicle's deceleration behaviour. *"Unevenness in deceleration immediately before stopping"*
Deceleration	Stereotype automated 'fixed deceleration'	$n = 21$ The majority of participants noted that the car braked early, and exhibited slow/patient driving. *"AD-like (not manual-like) because the speed from deceleration to stopping at the stop line is slow"*	$n = 18$ The majority of participants noted that the car braked early and exhibited slow/patient driving. It was also mentioned several times that the car exceeded the stop line. *"… The stop line is exceeded. Poor driving"*
Deceleration	Stereotype manual 'sudden stop'	$n = 22$ The majority of participants noted the car's late/sudden/aggressive braking. *"It feels like a machine that doesn't slow down to the last minute"*	$n = 20$ The majority of participants noted that the car's late/sudden/aggressive braking. *"Very aggressive driver … human because all the robots I've seen are very defensive"*
Deceleration	Stereotype manual 'crawling forward'	$n = 21$ The majority of participants pointed out that the car braked early or showed a slow/dull deceleration. *"It looks like an advanced self-driving car …"* *"… recognizing a pedestrian early in deceleration. If you cross the stop line, you cannot cross"*	$n = 22$ The majority of participants pointed out that the car braked early or showed a slow/dull deceleration. Many also mentioned that the vehicle exceeded the stop line. *"Driving poorly. Slow down too much from the front …"* *"The deceleration starts too early. There is no feeling of stopping because it moves forever"*

Note. The maximum possible sample size is 48 (i.e., twice the number of participants).

through a multi-stage process, consistent with Wickens' information processing model (see Wickens and Carswell, 2012). That is, first, participants perceive the car's behaviour, and then they make a decision/judgment about its automaticity. From our results, it seems that people are well able to perceive how a car behaves (e.g., driving in the lane centre). However, interpreting that behaviour and making a judgment about whether a car is driving automatically or manually may strongly depend on the participant's beliefs and preconceptions of what is typical manual or automated behaviour. As we showed, a particular vehicle behaviour could be attributed to human clumsiness or intelligence, or a computer bug or feature.

Our results further suggest that likeability and perceived intelligence depend on the vehicle's behaviour, not on who is believed to be in control. For example, a sudden stop was disliked and regarded as unintelligent, while participants were divided as to whether the car was driven manually or automatically. These claims are supported by the strong correlations in Table 3.

A limitation of this study is that participants could see the brake lights turn on when the vehicle was braking, which means that their ratings were affected not only by vehicle motion but possibly also by the more explicit brake lights. A second limitation was that the experiment was conducted in three sessions, with the participants standing next to each other in a group. The participants were instructed not to interact with each other, and the experimenters observed full compliance with the request. Nonetheless, the experiment deserves to be replicated in a one-pedestrian setting to eliminate any possible effects of being in a group. Thirdly, only five trajectory types and four deceleration types were examined. More research is needed to obtain a thorough insight into how the AVs driving style affects the perception of pedestrians. For example, the scenarios could be extended to higher speeds, such as highway driving, as well as more complex scenarios, such as city scenarios with multiple road users requiring a high level of machine intelligence. A fourth limitation is that the research was conducted with employees of a car manufacturer. The participants were likely familiar with the AV and its development, but not with its driving behaviour, because the vehicle paths and speeds were programmed by the authors without the involvement of the participants. A final limitation is that participants were instructed to pay close attention to the vehicle to rate its behaviour. In real traffic, participants cannot be expected to concentrate closely on approaching vehicles but may monitor approaching vehicles using peripheral vision. The generalisability of the present findings towards real traffic contexts ought still to be examined.

We conclude that AVs do not have to drive like a human to be liked by pedestrians. Furthermore, pedestrians believe that an AV is being driven manually when pre-recorded manual driving is replayed. Driving in the centre and driving at a constant speed are reasons for believing the car is driving automatically, whereas anticipation, curve cutting, and minor irregularities are reasons for believing the car is driving by a human. However, pedestrian ratings of whether a vehicle is driving manually or automatically were often mixed, suggesting that pedestrian judgments of whether a vehicle is driving automatically do not only depend on the vehicle's behaviour, but also on preconceptions of how automated cars typically behave.

Supplementary material

Supplementary material that includes instructions, questionnaires, and anonymous questionnaire data is available at https://doi.org/10.4121/14077352.

Declaration of competing interest

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

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Appendix

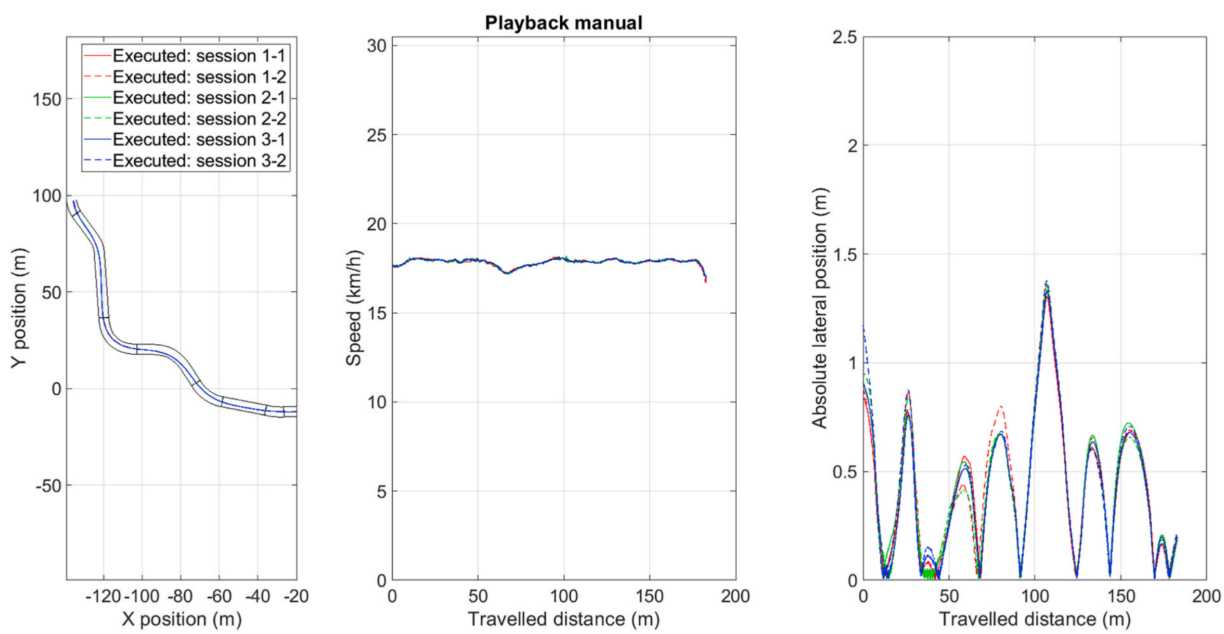

Figure A1. The playback manual driving trajectory. Left: top view. Middle: speed, Right: absolute lateral position.

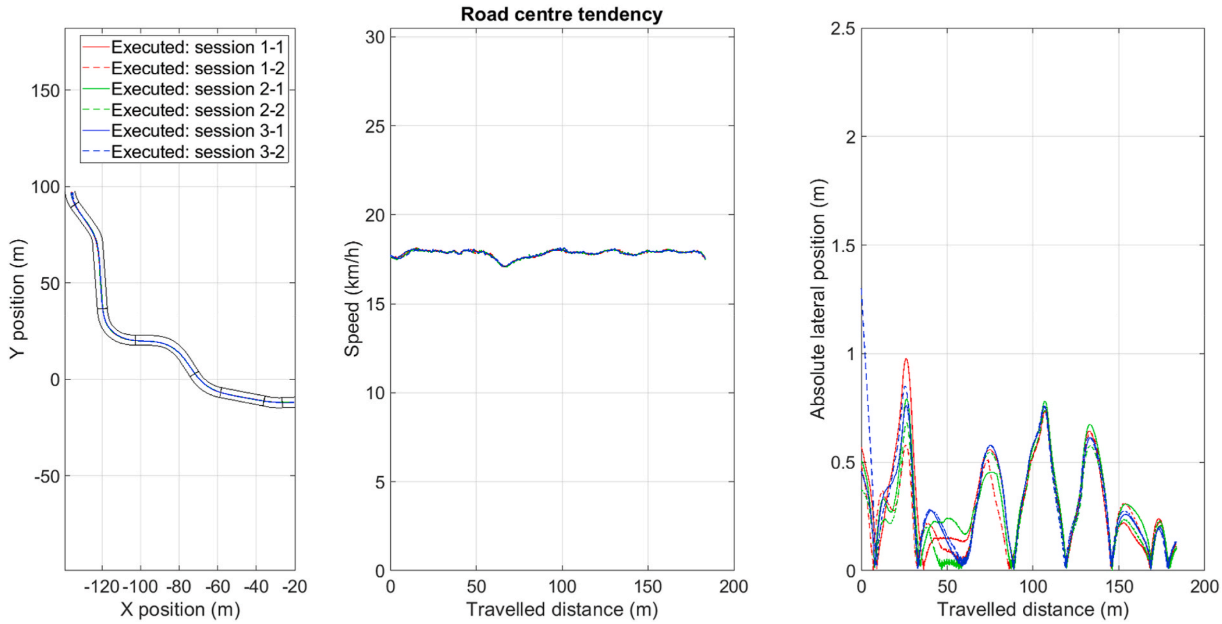

Figure A2. The stereotype automated ‘road centre tendency’ trajectory. Left: top view. Middle: speed, Right: absolute lateral position.

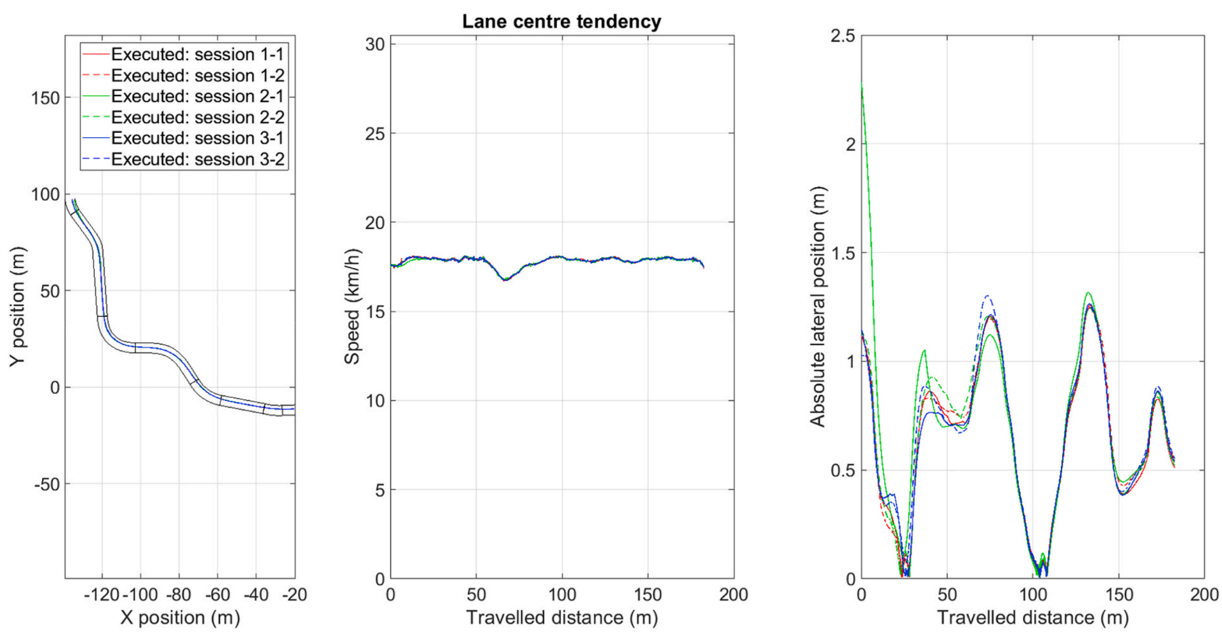

Figure A3. The stereotype automated ‘lane centre tendency’ trajectory. Left: top view. Middle: speed, Right: absolute lateral position.

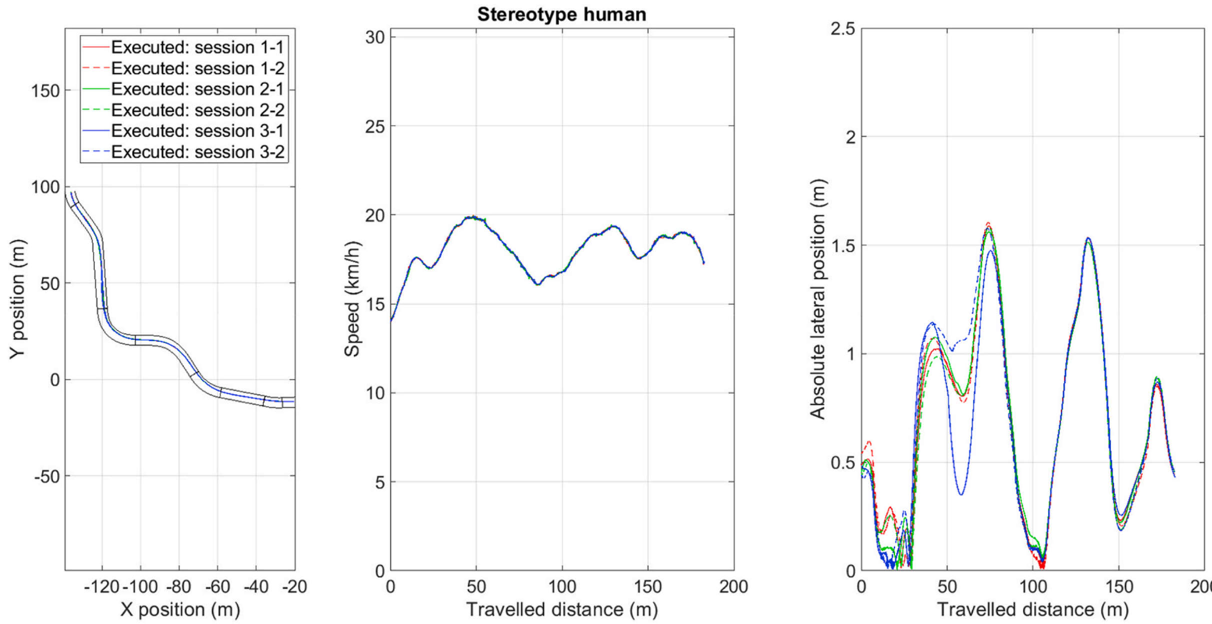

Figure A4. The stereotype manual ‘normal’ trajectory. Left: top view. Middle: speed, Right: absolute lateral position.

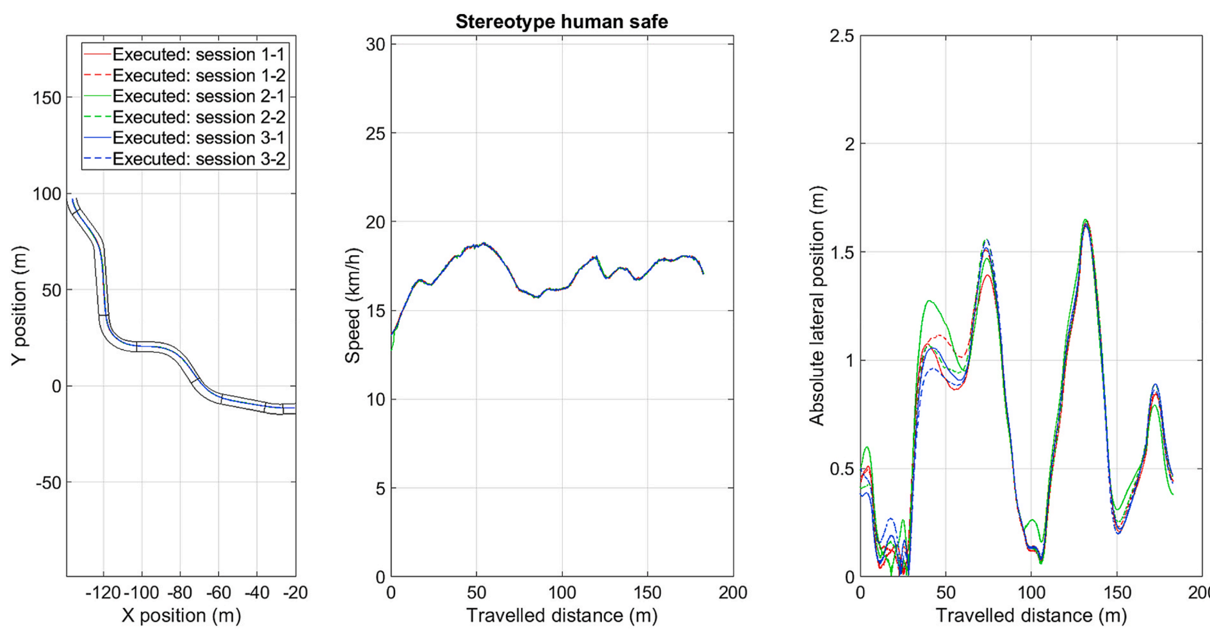

Figure A5. The stereotype manual ‘safe’ trajectory. Left: top view. Middle: speed, Right: absolute lateral position.

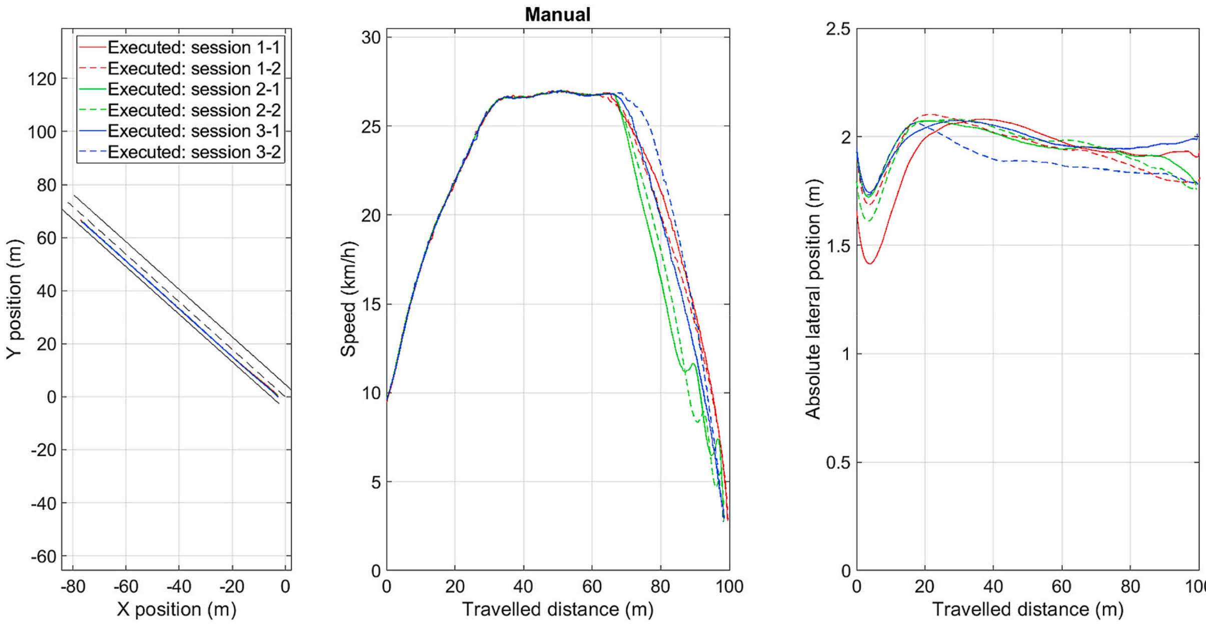

Figure A6. The manual braking profile. Left: top view. Middle: speed, Right: absolute lateral position.

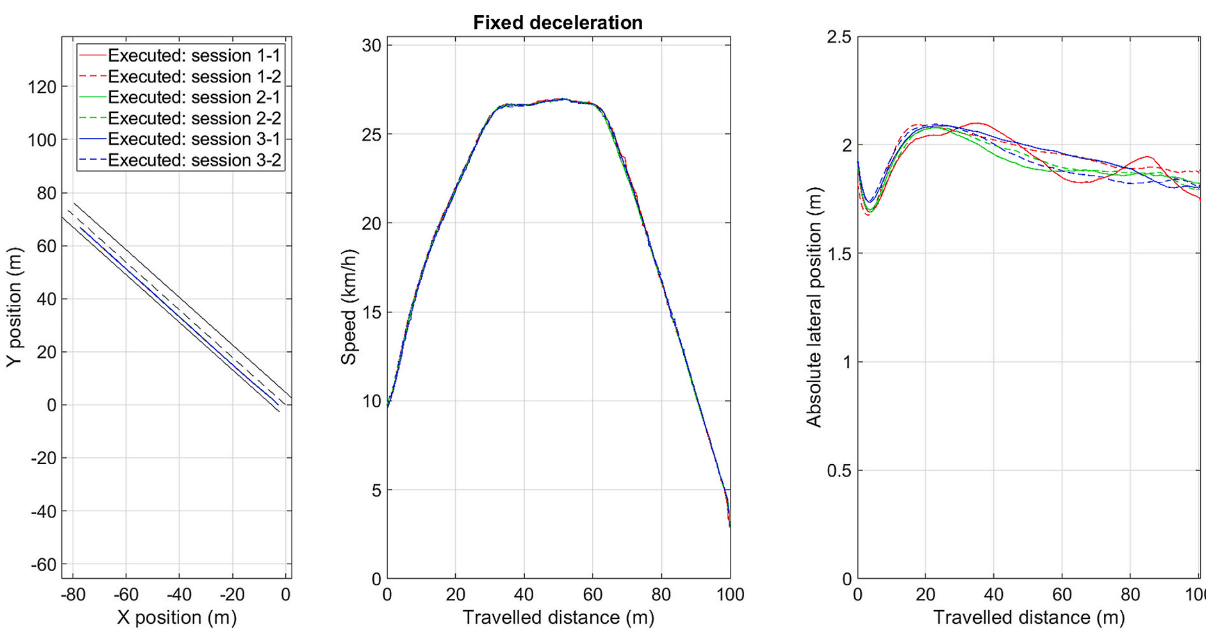

Figure A7. The stereotype automated ‘fixed deceleration’ profile. Left: top view. Middle: speed, Right: absolute lateral position.

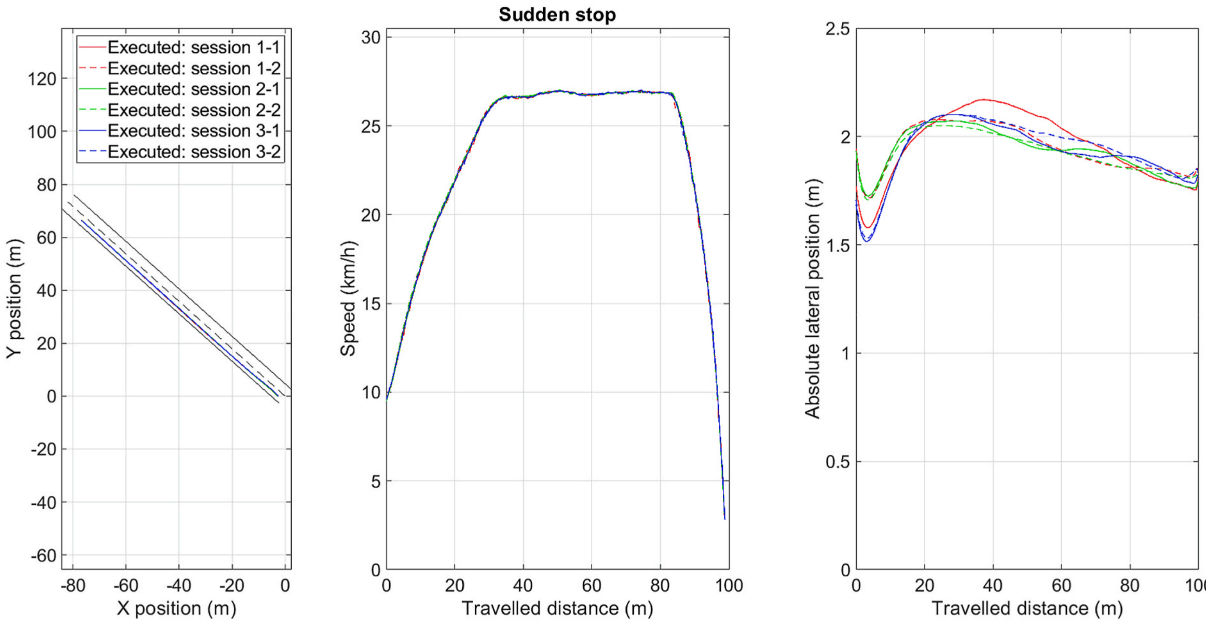

Figure A8. The stereotype manual 'sudden stop' deceleration profile. Left: top view. Middle: speed, Right: absolute lateral position.

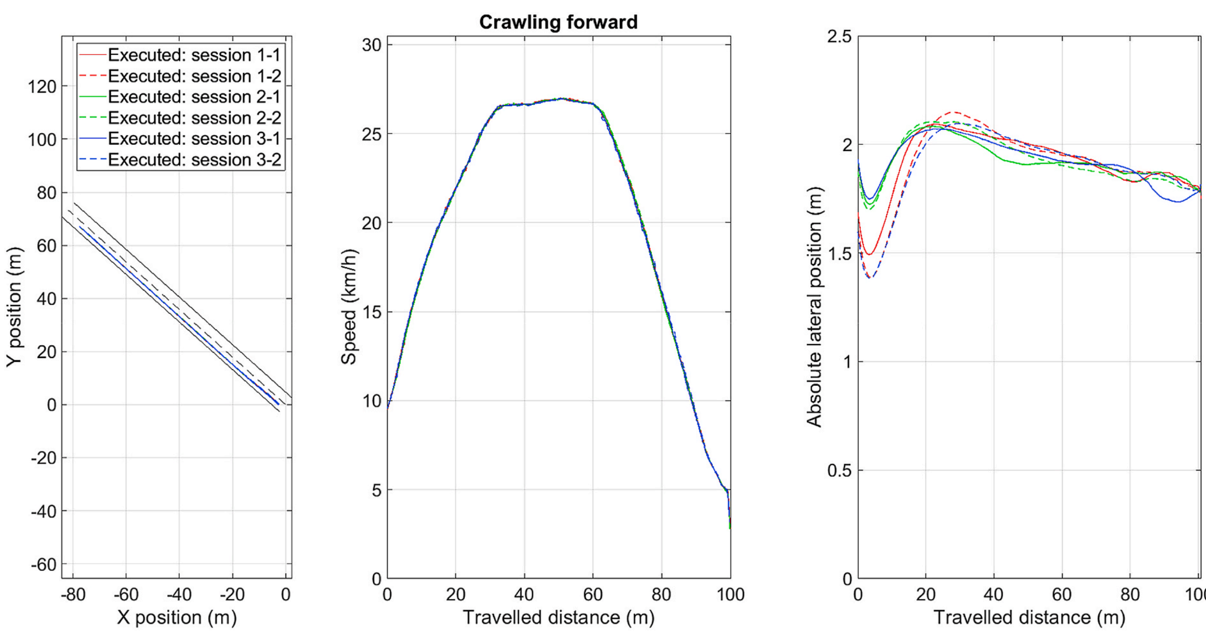

Figure A9. The stereotype manual 'crawling forward' deceleration profile. Left: top view. Middle: speed, Right: absolute lateral position.

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