Transition to Automated: The Interaction of Activating the In-vehicle Automated Driving System

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Abstract. Automated driving system (ADS) becomes more popularized in recent years, and the level 2 and level 3 ADS have already been equipped on several production car models in the market. The activating interaction of the ADS is very important since it is the very first step for users to manipulate and understand the system. However, most existing studies are focusing on the process of transition to manual—drivers taking over of the vehicles. We collected 21 different activating interactions that have already been equipped or proposed in production or concept cars, and explored their usability in a simulated driving environment with 30 recruited participants via a subjective evaluation. An experimenter measurement of the steering wheel turning angle was also included in order to compare the driving safety level between different activating interactions. With the ANOVAs of the usability score and steering wheel turning angle done, the result shows that six interactions "press the button on the right part of the steering wheel", "press the button on the left part of the steering wheel", "press the button on the center console", "pull the paddle behind the steering wheel on the right once", "pull the left and right paddles behind the steering wheel together once" and "keep pulling the left and right paddles behind the steering wheel for 1 s" are recommended for the ADS in terms of offering great usability and ensuring basic driving safety.

Keywords: Automated driving system · Activating interaction · Usability · Driving safety

1 Introduction

"The automated driving technology has the potential to fundamentally change road transportation and improve quality of life. Automated vehicles (AVs) are anticipated to reduce the number of accidents caused by human errors, increase traffic flow efficiency, increase comfort by allowing the driver to perform alternative tasks, and ensure mobility for all, including old and impaired individuals" [1, 2]. In recent year, this technology has become more and more popular and widely discussed. We could see some production car models that are already equipped with different levels of automated driving system in the market such as Tesla Model S and 2019 Audi A8.

Automated driving systems (ADS) are leveled in different ways. In this paper the NTHSA driving automation taxonomy (see Fig. 1) is adopted [3].

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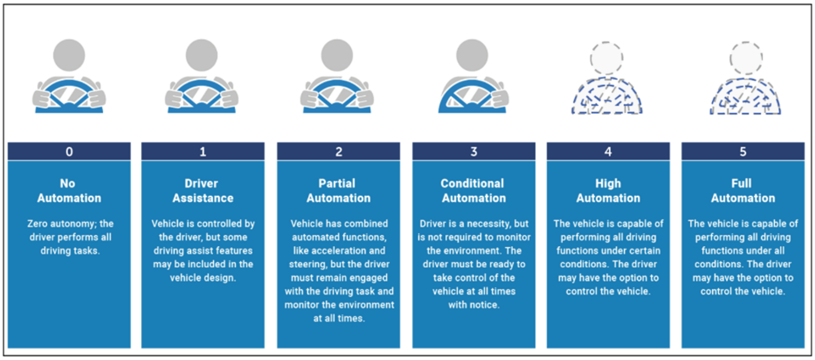

Fig. 1. The NHTSA driving automation taxonomy

Most existing product vehicles that are equipped with ADS have level 2 or level 3 automation capabilities. For example, Tesla's Autopilot with Hardware version 1 can be classified as somewhere between levels 2 and 3 [4], and the 2019 Audi A8's Audi AI system supports level 3 autonomous driving [5]. In Fig. 1, we could see that the level 2 automation is defined as "partial automation" which it requires that "the driver must remain engaged with the driving task and monitor the environment at all times", and the level 3 automation is called "conditional automation", the driver does not need to monitor the environment all the time, but has to take control of the vehicle when the system cannot keep working under certain circumstances. During a driving journey for a car that's equipped with level 2 or level 3 ADS, the automation is usually activated by the driver when it is available, and requires a takeover of the vehicle when the environment or the vehicle's condition no longer supports the automation. The driver must take over the vehicle with a certain manipulation, e.g. pressing the brake pedal immediately. So, for the whole process, activating and taking over are the two nodes that the human control and ADS intersect. Any mistake that happens in these nodes could incur potential road safety hazards. For example, in March 2018, a Tesla Model X fatal crash happened in California, U.S. because the driver didn't notice the takeover warning message that lasted for six seconds prior the crash [6]. This crash caused the car on fire and the death of the driver (see Fig. 2).

Fig. 2. Tesla Model X fatal crash site, March 2018, California

This accident raised a huge public debate, should the level 2 or level 3 ADS be equipped on product vehicles? How quickly can a distracted human turn to take control of the vehicle in what might be a sudden emergency [7]? We could see many scholars are researching on the safety issue of transition from automation to manual in the ADS. Such as the proper lead time of the takeover request [8] and the driver's driving stabilizing time after resuming control of the vehicle [9], etc.

However, with the plentiful and diverse existing research on the taking over side, we cannot see enough work on the activating side. When a driver initiates the ADS, the necessary interaction between the driver and the interior HMI (Human-machine-interface) could create potential accident risk e.g. driver distraction when the system is not yet turned automated [10]. So, it is important to provide the driver easy-to-use and un-distracting manual-to-automation (activating) interaction in the whole automated driving experience, and this needs a lot professional and systematic research.

In different L2 & L3-automated-driving-supported vehicles, the ADS is usually named in different ways such as Tesla's "Autopilot" [4], Audi A8 2019's "Audi AI Traffic Jam Pilot" [5], Volvo XC90's "Pilot Assist" [11] and Cadillac CT6 2018's "Super Cruise" [12]. Those vehicles are equipped with different hardware units that provide different activating interactions such as pulling a stalk behind the steering wheel, pressing a physical button on the steering wheel or a pressing physical button on the interior center console, etc. Different types of interactions have their pros and cons in terms of usability. We decided to investigate that through an experiment study among different existing activating interactions we collected via desk research.

We collected different activating hardware units from the existing production or concept cars models that are equipped with ADS including Tesla Model S, Audi A8 2019, Volvo XC90 2018, Cadillac CT6 2018, Volvo Concept Cockpit 26, Nissan Leaf 2018. Mainly there are three types of hardware units: button, stalk and paddle. These hardware units can be located in the following places: steering wheel front, steering wheel back and the center console (see Fig. 3).

Fig. 3. A pile of images of the existing ADS activating hardware units from production or concept cars

We listed all the possible locations & hardware unit types and there are totally 10 different variations: (1) a paddle behind the steering wheel on the left; (2) a paddle behind the steering wheel on the right; (3) a button on the left part of the steering wheel; (4) a button on the top part of the steering wheel; (5) a button on the right part of the steering wheel; (6) a button on the bottom part of the steering wheel; (7) a button on the left console; (8) a button on the center console; (9) a stalk behind the steering wheel on the left; (10) a stalk behind the steering wheel on the right.

For each type of hardware unit, based on the current common setups in modern production cars that we researched on there could be one or several interactions for each hardware: *(1) Button*: press once. (*2) Stalk*: pull downward once; pull upward once; pull forward once; pull backward once; pull backward twice. (*3) Paddle*: pull one paddle twice; pull two paddles once; keep pulling two paddles together for 1 s; keep pulling two paddles together.

So, considering about all 10 different hardware unit location variations, the number of the total activating interactions is 21, which is shown in the Fig. 4 below.

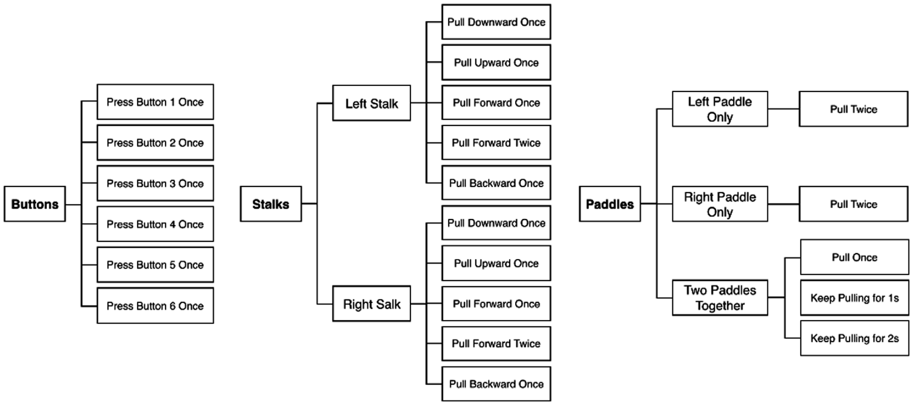

Fig. 4. Total 21 different activating interactions based on the collected hardware unit variations

According to the research of distraction in driving activities that was done by Tang, Wang, Shan and Zhu [16], the steering wheel turning angle is a key parameter to judge whether a certain in-vehicle manipulation or interaction could distract the driver and generate potential hazard and it was involved in this research to evaluate the driving safety level of different activating interactions.

The objective of this research was to figure out which one or several of those 21 interactions could offer great usability and ensure the basic safety of driving. Results could help and provide strong theoretical basis for the interior design of our own autonomous-driving demo car and offer recommendations of selecting ADS activating hardware units for those automotive OEMs we will cooperate with in the future.

2 Experiment Design

2.1 Participants

Thirty participants (21 males, 9 females, according to the Chinese driver gender ratio which is approximately 7:3 in 2017 [13]) ranging from age 18 to 44 (M = 29.57, SD = 2.67) years of age took part in this laboratory experiment. Their reported years of driving experience ranged from 0.5 year to 10 years (M = 3.6, SD = 2.81). All of them had normal or corrected-to-normal vision, valid driver licenses, and had driven within the past month. Participants were compensated with 100 RMB/hour. Written informed consent was obtained prior to the experiment.

2.2 The Simulated Driving Environment

We set up the simulated in-cockpit environment in our research laboratory in Beijing (see Fig. 5) in order to investigate how users would react and behave to the ADS activating scenarios. This simulated environment was built using the Pinguanfeida driving simulator. This simulator includes a steering wheel with embedded buttons, stalks and paddles, an accelerator & brake pedal set, a monitor that's placed on a table could display a virtual driving track and people could actually drive a car on that track with controlling the accelerator and brake. All 10 activating hardware units were embedded in this simulated environment: (1) a paddle behind the steering wheel on the left (left paddle); (2) a paddle behind the steering wheel on the right (right paddle); (3) a button on the left part of the steering wheel (button 1); (4) a button on the top part of the steering wheel (button 2); (5) a button on the right part of the steering wheel (button 3); (6) a button on the bottom part of the steering wheel (button 4); (7) a button on the left console (button 5); (8) a button on the center console (button 6); (9) a stalk behind the steering wheel on the left (left stalk); (10) a stalk behind the steering wheel on the right (right stalk).

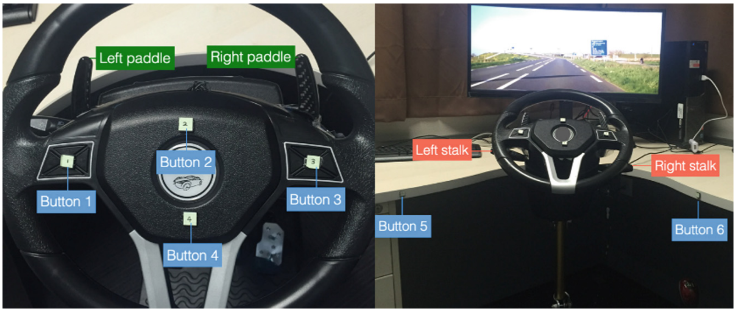

Fig. 5. The simulated environment

2.3 Usability Evaluation Criteria

Prior to the experiment, we did an expert discussion that includes four in-vehicle experience design professionals trying to discover what principles could be adopted for evaluating the usability of activating the ADS based on the key factors from several existing in-vehicle or in-aircraft user experience studies, such as "user could learn from previous experience" [14], "the system should prevent manipulating errors" and "the manipulation could be reached within a short distance" [15], etc. We collected the key findings and summarized, generally there are five key principles could be worth considering and adopted as the usability test criteria: (1) *Error prevention*. How a certain interaction or experience process in the HMI system could be done with a low chance of accidentally making an error; (2) *Co-existing with other manipulations*. How a certain interaction or experience process could be done without affecting other interaction or experience process; (3) *Easy to reach physically*. How a certain interaction or experience process could be easily initiated by moving any body part for a short distance; (4) *Comfortable to manipulate*. How a certain interaction or experience process could be done in a comfortable way; (5) *Easy to learn from previous experience*. How a certain interaction or experience process could be easily learnt from previous experience of using the same type of products.

All participants were asked to marked the above five criteria from 1–5 (1 stands for not important at all, 5 stands for very important), and we got the mean value of each criteria's score *(x)* and a clear importance ranking. This result would help us to evaluate the general score for each activating interaction finally (will be explained later). The marking result is shown in Fig. 6 below.

Criteria	Error prevention	Co-existing with other manipulation	Easy to reach physically	Comfortable to manipulate	Easy to learn from previous experience
Score *(x)*	4. 58	3. 08	2. 73	2. 5	2. 12
Importance	★★★★★	★★★★	★★★	★★	★

Fig. 6. Usability test criteria marking and the importance ranking result

We could clearly see a ranking order: The "error prevention" is considered as the most important usability criteria. And the "easy to learn from previous experience" is considered as the least important one.

2.4 Experiment Design and Procedure

The experiment was conducted as a within-subjects design. The independent variables were the 21 ADS activating interactions, the dependent variables were the usability evaluation score of each interaction from the participant evaluation result and the steering wheel turning angle from the experimenter measurement result.

The usability score of each ADS activating interaction from the participant evaluation was considered as the mainly-considered result because the main goal of this experiment is comparing the usability between different ADS activating interactions. The steering wheel turning angle from the experimenter measurement was only used to filtrate the good-usability activating interactions to ensure the basic driving safety.

Participant Evaluation. Firstly, each participant was asked to understand the background of this experiment and get familiar with all the software and hardware in the simulated environment in five minutes. Secondly, each participant was asked to manipulated all 21 activating interactions in a completely random order. For each round, the driving will drive the "car" in virtual track. When it went on the straight road (the virtual car is hard to control on curved road), the experimenter would send a message "automated driving is available now" to the monitor, and the participant needs to activate the ADS via a certain interaction immediately. When the activation is successfully done, the screen message is turned to "automated driving successfully activated" and the screenshot of the monitor at that moment will be taken automatically. All participants were asked to activate the ADS via all 21 types of functions in a completely random order (Fig. 7). After each round, the participant is required to evaluation the certain activating interaction based on the five usability criteria by marking from 1–5 (1 stands for not matched at all, 5 stands for very well matched) and filling out a form.

Fig. 7. The experiment in process

Experimenter Measurement. During each round of the experiment for each participant, the steering wheel turning angle is measured from the monitor screenshot of the successful activating moment, it is 100% matched with the physical steering wheel's turning angle. We leveled the turning angle for 5 levels based on the maximum turning angle and the minimum turning angle we observed during the whole experiment: "1" represents very subtle turning (0°–5°); "2" represents subtle turning (5°–10°); "3" represents normal turning (10°–15°); "4" represents obvious turning (15°–20°); "5" represents very obvious turning (20°–25°).

3 Result

3.1 Participant Evaluation Result

Under each usability criteria there are 21 mean value score of the 21 activating interactions from 30 participants' evaluation result (see Figs. 8, 9, 10, 11 and 12). Hence, each activating interaction has 5 usability criteria scores (*f*). If we use this 5 usability-criteria scores to multiply its importance score (*x*) that has been mentioned above, we would get a total usability score (*T*) for each interaction (Table 1).

$$T = x1f1 + x2f2 + x3f3 + x4f4 + x5f5 \quad (1)$$

Repeated measures ANOVA revealed that the total usability scores of 21 activating interactions were significantly different from each other ($F\ [6.24,\ 181.08] = 7.65$, $p = 0.001$). Bonferroni post hoc analyses indicated that there was no significant

Fig. 8. Usability score of the 21 activating interactions under "Error prevention" criteria

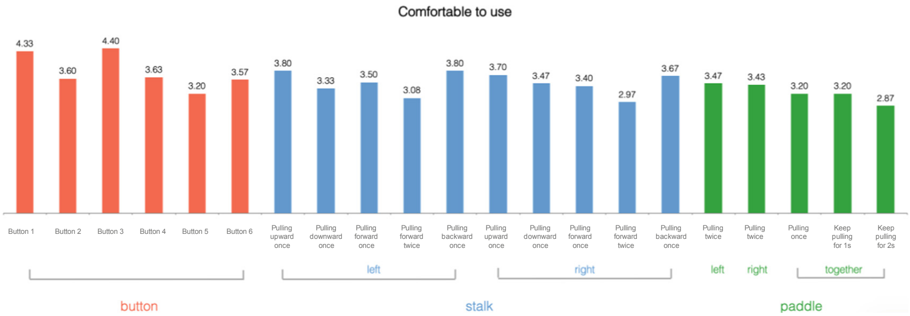

Fig. 9. Usability score of the 21 activating interactions under "Comfortable to use" criteria

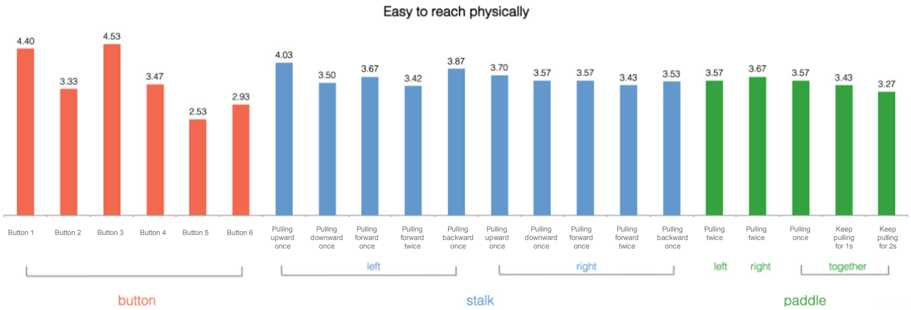

Fig. 10. Usability score of the 21 activating interactions under "Easy to reach physically" criteria

difference between the top-eight usability interactions "press the left button on the steering wheel once", "press the right button on the steering wheel", "press the button on the center console once", "pull the left paddle twice", "pull the right paddle twice", "Pull left and right paddles together once", "keep pulling left and right paddles for 1 s" and "keep pulling left and right paddles for 2 s". This means that from the participants' perspective these interactions have no difference in terms of usability.

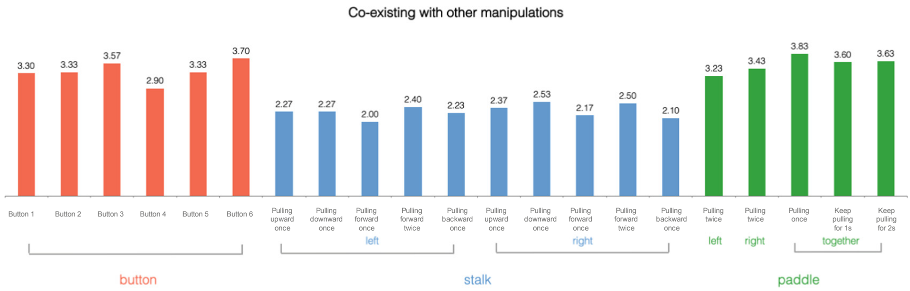

Fig. 11. Usability score of the 21 activating interactions under "Co-existing with other manipulations" criteria

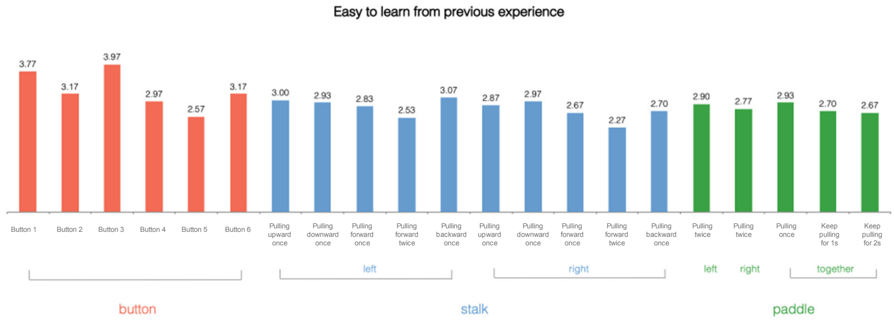

Fig. 12. Usability score of the 21 activating interactions under "Easy to learn from previous experience" criteria

3.2 Experimenter Measurement Result

We collected the data of the steering wheel turning angles of all 21 interactions for each participant, and matched those angles with different levels that has been mentioned in the "experimenter measurement" section. Then we calculated the mean value of all 30 participants' steering wheel turning level for each interaction. The result is shown in Fig. 13 below.

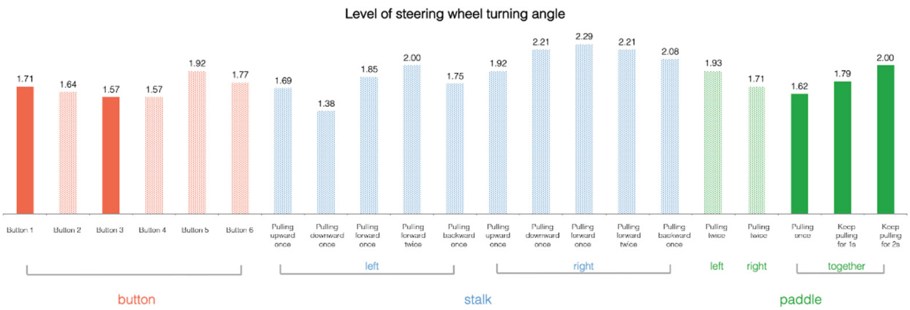

Fig. 13. Mean steering wheel turning level of 21 activating interactions

We could see that the mean steering wheel turning level of the top-eight interactions ("press the left button on the steering wheel once", "press the right button on the steering wheel", "press the button on the center console once", "pull the left paddle twice", "pull the right paddle twice", "Pull left and right paddles together once", "keep pulling left and right paddles for 1 s" and "keep pulling left and right paddles for 2 s") from the participant evaluation result respectively are: 1.71, 1.57, 1.77, 1.93, 1.71, 1.62, 1.79, 2.00. Repeated measures ANOVA revealed that these 8 steering wheel turning level of activating interactions were significantly different from each other ($F[4.56, 132.24] = 2.62$, $p < 0.05$). Bonferroni post hoc analyses indicate that steering wheel turning level of "pull the left paddle twice" and "keep pulling left and right paddles for 2 s" were significantly greater than other 6 activating interactions ($ps > 0.05$).

Table 1. Total usability score (T) for 21 activating interactions

		Criteria importance	Error prevention	Co-existing with other manipulations	Easy to reach physically	Comfortable to manipulate	Easy to learn from previous experience	Total score (T)
			4.58	3.08	2.73	2.50	2.12	
Button	Press button	Button 1	2.87	3.30	4.40	4.33	3.77	54.12
		Button 2	3.17	3.33	3.33	3.60	3.17	49.58
		Button 3	2.73	3.57	4.53	4.40	3.97	55.29
		Button 4	3.03	2.90	3.47	3.63	2.97	47.66
		Button 5	3.80	3.33	2.53	3.20	2.57	48.03
		Button 6	3.53	3.70	2.93	3.57	3.17	51.22
Stalk	Left	Pull upward once	2.27	2.27	4.03	3.80	3.00	44.23
		Pull downward once	2.47	2.27	3.50	3.33	2.93	42.39
		Pull forward once	2.17	2.00	3.67	3.50	2.83	40.85
		Pull forward twice	2.83	2.40	3.42	3.08	2.53	42.78
		Pull backward once	2.37	2.23	3.87	3.80	3.07	44.28
	Right	Pull upward once	2.40	2.37	3.70	3.70	2.87	43.71
		Pull downward once	2.50	2.53	3.57	3.47	2.97	43.95

(*continued*)

Table 1. (*continued*)

		Criteria importance	Error prevention	Co-existing with other manipulations	Easy to reach physically	Comfortable to manipulate	Easy to learn from previous experience	Total score (T)
			4.58	3.08	2.73	2.50	2.12	
		Pull forward once	2.57	2.17	3.57	3.40	2.67	42.32
		Pull forward twice	3.13	2.50	3.43	2.97	2.27	43.65
		Pull backward twice	2.27	2.10	3.53	3.67	2.70	41.39
Paddle	Left	Pull twice	3.52	3.23	3.57	3.47	2.90	50.62
	Right	Pull twice	3.23	3.43	3.67	3.43	2.77	49.84
	Both	Pull once	4.03	3.83	3.57	3.20	2.93	54.24
		Keep pulling for 1s	4.00	3.60	3.43	3.20	2.70	52.51
		Keep pulling for 2s	4.37	3.63	3.27	2.87	2.67	52.93

4 Conclusion

The participant evaluation result provided eight activating interactions that could offer great usability, and the experimenter measurement result of the steering wheel turning angle helped us narrow down the number to six in terms of ensuring the basic driving safety. Generally, six activating interactions: "press the left button on the steering wheel once", "press the right button on the steering wheel", "press the button on the center console once", "pull the right paddle twice", "Pull left and right paddles together once" and "keep pulling left and right paddles for 1 s" obviously exceed other fifteen interactions in terms of offering great usability and ensuring the basic driving safety.

5 Discussion

This research could help us establish a systematic usability evaluation method for the ADS activating interaction including the five key evaluation criteria. It also has important reference value for other ADS user experience research, e.g. driver take-over the control of a vehicle from ADS. The experiment result allowed us to narrow down the total twenty-one activating interactions to six with regard to providing great usability and ensuring driving safety, it generated great tips of the autonomous vehicle interior design for OEMs and our demo car in the future.

There were some limitations in our project that we did not consider or could not improve when we conducted this research. (1) the simulated environment we built could not 100% simulate the real on-road environment. For example, when placing the buttons on the table we did not consider enough ergonomic issues, so in a real cockpit these buttons could be easier or harder to reach and manipulate and that might influence the result of the experiment. (2) The steering wheel we used in the simulated environment did not offer the same level of resistance that a real steering wheel could offer. And the turning angle data we collected is not realistic enough. In a real driving scenario, pressing a button on the steering wheel may only cause a 2° turning. And different interactions may not show obvious differences in steering wheel turning angle. (3) We did not consider that the participants could be left-handed or right-handed, that this would influence usability evaluation results of the left-hand side interactions (e.g. press the button on the left part of the steering wheel) and the right-hand side interactions (e.g. press the button on the left part of the steering wheel).

In the future, first of all, we will keep investigating this topic by doing more experiments with the existing problems revised in an improved simulated driving environment based on the findings of our project, e.g. investigating the ergonomics of the ADS activating paddle design. Secondly, other types of activating interactions would be focused on such as voice control, hand gesture control and multi-touch control. Lastly, other user experience attributes will be investigated. According to Marc Hassenzahl's UX theory of pragmatic and hedonic attributes of products, from the user perspective, the pragmatic attribute could provide the functionality and ways to access functionality, to fulfill externally given or internally generated behavioral goals. And the hedonic attributes emphasize individuals' psychological well-being [17]. For the activating interaction of ADS, the hedonic attribute could possibly make ADS – a relatively new thing in people's life more appealing and interesting. It would be icing on the cake for the ADS when the basic pragmatic needs are fulfilled, and that is worth researching on.

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