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Spatial Components Guidelines in a Face-to-Face Seating Arrangement for Flexible Layout of Autonomous Vehicles

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Abstract: Fully autonomous vehicles are not yet available for consumers to experience; however, as experts predict they will be ready for the consumer market in the not-too-distant future, it is important to consider the spatial design of such vehicles. As the interior of a vehicle is a confined space, it is important to design a flexible layout in different aspects of the overall space. Therefore, this study aimed to analyze the relationships among various elements related to the use of space in a face-to-face seating arrangement. Using mock-up, observational surveys, questionnaires, and the think-aloud research method within an ethnographic observation framework, we conducted experiments on three study participants who were aware of the changing concept of autonomous vehicles. One of the key findings of our analysis is that various activities and actions can occur in a face-to-face seating arrangement. It is important to recognize that face-to-face seating arrangements are not just to facilitate conversation but can be seen as an environment in which each passenger can conduct other in-vehicle activities individually. Based on these findings, we recommend that needs for activities be considered when designing spatial components in a face-to-face seating arrangement.

Keywords: autonomous vehicle; spatial design element; face-to-face seating arrangement; in-vehicle activity; mock-up of vehicle interior

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Citation: Kwon, J.; Ju, D. Spatial Components Guidelines in a Face-to-Face Seating Arrangement for Flexible Layout of Autonomous Vehicles. *Electronics* **2021**, *10*, 1178. https://doi.org/10.3390/electronics10101178

Academic Editor: Michael Wehner

Received: 13 April 2021
Accepted: 11 May 2021
Published: 14 May 2021

1. Introduction

Developments in the technology needed to produce fully autonomous vehicles are accelerating, with the goal of commercializing such vehicles in 2025–2030 [1–3]. Accordingly, in addition to a focus on the technology for autonomous vehicles, there is great interest in how the user experience in a vehicle is likely to change when the driver does not have to drive. As occupants of these vehicles will be able to perform various activities en route to their destinations, there are various technologies and features that cover a wide range of perspectives regarding the user experience being developed, including how the occupants will interact with the vehicle and the design of spaces to suit various types of activities. The technologies and features presented to date have started by considering how best to take advantage of the time available to the occupants of autonomous vehicles.

Automotive manufacturers and related IT companies are focusing on research and development efforts that will maximize user's experience, thereby supporting in-vehicle activities and applying spatial arrangement flexibly within the confined space of the vehicle. Some previous studies focused on drivers' needs and conducted an experiment based on the interaction between driver and autonomous vehicle [4–7]. To take full advantage of fully autonomous vehicles, it is necessary to approach their design with a new concept of a moving living space, and driver-centered research needs to be shifted toward passengers in the overall context of in-vehicle activities.

Few studies have been conducted to analyze user's perspective in this new paradigm, and the technologies and features that can be applied to autonomous vehicles to create user-centric spatial design plans. Research on the user experience within autonomous vehicles is limited [8–10], partially due to the difficulties of investigating something that does not yet exist [11]. Therefore, the issue of how best to evaluate user's expectations and behaviors with respect to interacting with, and the interior design of fully autonomous vehicles remains an open research question. Researchers who study autonomous vehicle interior design have explored user's expectations using various methodologies in the design field. Studies have been conducted to interview or analyze the actions of participants who experienced autonomous vehicles using simple prototypes and driving simulators [7,9,11,12]. Several studies have provided participants with a hands-on experience through seating buck, and have explored their expectations [7,12]. Previous studies found that first-hand experience with autonomous vehicles via prototypes and driving simulators helped participants to develop a realistic understanding of these vehicles [12].

The passenger experience in fully autonomous vehicles can be predicted through concept vehicles created by automobile manufacturers and related IT companies, and through studies related to autonomous vehicles' spatial design and in-vehicle activities. Consumer preferences for seating arrangements that allow occupants to face each other and communicate with each other are emerging [9,11]. Studies have been conducted to identify in-vehicle activities, actions, and seating positions preferred by users, but studies that analyze passengers' behaviors based on specific usage cases in an autonomous vehicle to fully understand their needs are incomplete. Subdividing and analyzing spatial elements within specific contexts can address the problem whereby various spatial components can interfere with passengers in the vehicle's confined space. It is also an important way to consider problems in which the user's body interferes with the vehicle's components, or where the user is not able to use certain components when the seating arrangement changes. This study aimed to analyze the relationships among various elements related to the use of space in a face-to-face seating arrangement of an autonomous vehicle. Using a mock-up of the interior space of an autonomous vehicle, we analyze how best to create a user-centered, efficient passenger space in an autonomous vehicle. The study results can be used to develop a flexible approach to designing the spatial components of autonomous vehicles, which is the subject of significant research and development efforts among automobile and technology developers.

Several studies have been conducted with a fragmented approach, focusing on individual elements such as how passengers interact with technology inside the vehicle and the need for seats. To understand spatial design elements according to the complete user experience, this study uses the spatial components suggested in a concept car and seating shown in mock-ups in previous studies. In this respect, our study differs from previous studies. Using this approach, it is possible to implement an optimized flexible layout to accommodate spatial designs differentiated by users and scenarios. Therefore, the study results are significant for academic researchers and the fully autonomous vehicle industry.

2. Literature Review

2.1. Changes in the Interior Space of Autonomous Vehicles

As the interior space of an autonomous vehicle is defined as a living space, it is expected that there will be significant changes made to this space compared to traditional vehicle interiors. Accordingly, automobile manufacturers and related IT companies are developing technologies and designs that differ from existing vehicles by focusing on the user experience. In particular, in fully autonomous vehicles, the concept of a four-person face-to-face seating arrangement has been introduced, focusing on the ability to rotate the seats 180° to change the spatial environment, and also on components related to the seat rotation technology (Table 1). For autonomous vehicles that are expected to be available in the fairly near future, a face-to-face seating arrangement has been proposed where the seats of the front and rear passengers face each other even if the driver's seat is not completely rotated 180° (Table 1). In this study, we used one face-to-face seating arrangement only for passengers (excluding the driver's seat) and a face-to-face seating arrangement for all passengers, including the driver's seat, as would be possible in a fully autonomous vehicle.

Table 1. Analysis of the spatial design of the autonomous vehicle concept of the face-to-face seating arrangement and in-vehicle activities.

Concept/Year	Autonomous Driving Level *	In-Vehicle Activities	Spatial Components
Volkswagen, BUDD-e/ 2016 [13]	Level 2 or higher	- Face-to-face conversation - Entertainment	- Swiveling and folding function of the passenger seat - Large display built into the dashboard - Sofa-shaped rear seat design - Wood and carpet floor
Volkswagen, I.D. Buzz/ 2017 [14]	Level 2 or higher	- Face-to-face conversation	- Swiveling function of the passenger seat - Folding steering wheel - Sliding center console - Folding table out from the center console - Center console display - Wood floor
Toyota, Fine-Comfort Ride/2017 [15]	Level 4 or higher	- Face-to-face conversation	- Swiveling function for all seats - Folding steering wheel - Relax seat - Mood lighting - Display situated on the doors
Aston Martin, Lagonda Vision concept/2018 [16]	Level 4 or higher	- Face-to-face conversation - Rest and sleep	- Swiveling function of the passenger seat - Relax seat and blanket - Display for the rear seat(Applied to the front seat back) - Center console display - Mood lighting - Carpet floor
Volvo, 360c/2018 [17]	Level 5	- Face-to-face conversation - Rest and sleep - Eating a meal/snack - Work/Read a book	- Sofa-shaped seat design and face-to-face seating arrangement - Relax seat and blanket - Display situated on the doors - Steering wheel removal - Carpet floor
Bosch, IoT Shuttle/ 2018 [18]	Level 5	- Face-to-face conversation - Entertainment - Video call	- Face-to-face seating arrangement - Steering wheel removal - Movable display applied to each seat - Display situated on the doors

* The autonomous driving level follows SAE J3016 standards [19].

2.2. Prior Research on In-Vehicle Activities and the Spatial Design of Autonomous Vehicles

Research related to the spatial design of autonomous vehicles can be largely classified into studies that analyzed in-vehicle activities, seating arrangements, and designs for individual spatial components. These studies used questionnaire surveys or interviews, and as most of the study participants had no experience with autonomous vehicles, experiments were conducted using a stationary vehicle, simulator, or laboratory environment.

To predict in-vehicle activities that are likely to occur in future autonomous vehicles, previous studies mainly surveyed consumers' preferred activities using the research techniques and simulated setting mentioned above [20–23]. Pfleging et al. conducted online and in situ surveys and observed the activities of passengers on the subway [21]. Schoettle and Sivak conducted an online survey of citizens of English-speaking countries, the U.S., the U.K., and Australia to investigate awareness about autonomous vehicles [22]. In a study by Ive et al., participants approached and entered a vehicle and were asked to imagine that it was an autonomous vehicle [23]. They were then demonstrated how they might engage in various activities.

One of the big changes in the interior space of an autonomous vehicle is likely to be a change in the arrangement and shape of the seats. To study needs for the seating arrangement and function, experiments were conducted in an actual vehicle and experimental environment of an autonomous vehicle. Pettersson drew the exterior shape of a car in chalk on the floor of a parking lot and placed a few chairs within the outline so that the study participants could express their preferences based on the actual size of the likely interior space of an autonomous vehicle [9]. In a study by Jorlöv et al., participants were interviewed in a minimalist setting consisting of four chairs in front of a sketch of a Mercedes-Benz F015 [11]. A related study was conducted in a driving simulator that replicated the actual vehicle environment. In a study by Large, Burnett, Morris, Muthumani, and Matthias, participants were asked to act as if they were in an autonomous vehicle by using their own objects/devices [7].

Some studies were conducted to suggest design plans for individual spatial components of an autonomous vehicle. Filo proposed a conceptual design with a focus on functionality that could be implemented in future autonomous vehicles [24]. Some studies have analyzed the relationship between in-vehicle activities and the functions of various spatial components, but as the interior of a vehicle is a confined space, it is important to design a flexible layout in different aspects of the overall space. It is also important to allow users to experience the interior space of an autonomous vehicle that will change in the future to consider whether the proposed spatial design is appropriate and analyze the spatial design elements. Some studies used an existing vehicle model (seating buck) to assess various approaches to spatial design such as usability and ergonomics [25]. It is important to investigate the user experience in an autonomous vehicle model (seating buck) that incorporates a flexible spatial design in which the participants can freely use various components in the space.

2.3. Prior Research on User Action and Spatial Design

A user-centered design should incorporate the elements that influence the user's action patterns within the given environment, and many studies have emphasized the importance of context in the design process [26]. Context refers to all of the information that characterizes a given situation, including people, places, and objects related to interactions between users and systems [27]. In designing the user experience, context can refer to an element that affects the user's action patterns and motivation for using a certain product or service. According to Barker, there is an inter-relationship between the physical environment and a fixed action pattern in terms of action setting theory [28]. Accordingly, the study of actions in isolation is of little significance; the physical composition and conditions of the place where the action occurs must be included.

To this end, much research has been conducted on spatial design to understand the relationship between user actions and environmental characteristics using the observation method. This was originally referred to as ethnography, which studies a social organization or unique lifestyle of a group of people. Several studies have been conducted by observing user actions in real environments from an ethnography perspective, and other studies have used observation methods in a laboratory environment in the case of spaces and products that do not actually exist.

2.4. AEIOU Framework

To understand action patterns and phenomena that occur between users and spaces, several studies have focused on awareness and processes of user activities and action systems. Among the systems of analysis that define the elements of observation, the Doblin Group, John Zeisel, and Michael Quinn Patton's analysis systems are representative. In particular, the five elements of the Doblin Group (activities, environments, interaction, objects, and users, hereinafter AEIOU) are widely used in the design field, although there is a view that this range is relatively narrow (Table 2) [29]. However, in this study, our analysis was conducted using the Doblin Group's AEIOU Framework to analyze physical spatial design elements by focusing on the relationship between the physical environment and user actions.

Table 2. AEIOU Framework.

AEIOU		Explanation
A	Activities	An activity is a specific set of actions with a goal to achieve
E	Environment	Environment refers to the entire area, including personal, and public spaces, and time in which actions take place, and includes the nature and function of each space, and contextual system
I	Interaction	Interaction refers to the interaction that exists between people and people, people and things, and people and space
O	Object	Objects are the most basic elements of the environment and include tools that people use for specific purposes through their activities in the environment
U	User	Users are the subjects to be observed. Their roles and relationships, values, and dispositions are included. There is a subject and a sub-subject of action

3. Materials and Methods

3.1. Procedure and Measurement

We use a qualitative method in this study, namely the observation method, which observes subjects' actions in using space. Observations and interviews are useful approaches to gaining a deep understanding of subjects' specific actions [30]. In addition, the concurrent think-aloud method where subjects express their thoughts in words during the experiment, and the survey method where subjects write thoughts and opinions that were not spoken during the think-aloud portion of the experiment, are beneficial. Concurrent think-aloud, which we use in this study, has been widely used in previous studies to identify important elements of the user experience and is a technique that allows an observer to grasp users' intentions. Detailed research was conducted using video observation, concurrent think-aloud, and survey methods (Table 3).

First, to predict the orientation of the spatial design of an autonomous vehicle and select the range of in-vehicle activities, we analyzed designs of autonomous passenger vehicles that automobile manufacturers plan to introduce in the future and reviewed existing studies on this topic. Second, prior to being observed, study participants were asked to consider the activities they might want to undertake in an autonomous vehicle. Participants were allowed to freely experience the activities they had selected using components in the mock-up of the autonomous vehicle. Third, to analyze user actions within a given context, we conducted our research via observations in a laboratory setting with a physical mock-up of a vehicle interior, given that the actual autonomous vehicles, even concept cars, are not yet commercially available. One of the observation methods used was video ethnography. In the field of design, video ethnography was used by the Dublin Group in the mid-1990s for user observations. It is a traditional research method used to analyze the subject of research in social sciences and has been actively used to identify users' hidden needs.

This study presented in-vehicle activities, including both short and long-distance movements of autonomous vehicles. To apply the results of this study to various conditions and use cases, the relationship between detailed activities, actions, and spatial components was identified according to the overall context. The results of this study include in-vehicle activities that can be performed even on short distances movements (e.g., face-to-face conversation, using a cell phone, and inaction) and in-vehicle activities that can be performed in long-distance movements (e.g., sleeping and reclining, activities that use table, eating meals and snacks, watching video). Travel time can affect in-vehicle activities and passenger behavior. Not only travel time, but also the purpose of movement, passenger characteristics, number of passengers, and composition of passengers have a complex effect on in-vehicle activities and passengers' behavior, so it is necessary to design a flexible layout for each use case. The purpose of movement includes daily life such as short-distance shopping, commuting, leisure, and travel. In the future, an autonomous vehicle will not be used only for mobility purposes. It can be used as a living space even in a stationary condition. If an autonomous vehicle is defined as the living space, the use case should be considered and a flexible layout that can accommodate various in-vehicle should be designed in consideration of the use case.

Table 3. Contents of the survey.

Survey Item	Contents
Preferred in-vehicle activities	Choose three of the following in-vehicle activities experiences: personal work, reading a book, appearance management (makeup, changing clothes), eating meals/snacks, meditation and thinking, sleeping and reclining, face-to-face conversation and play, video/voice/text/mail communication, listening to music, watching TV or movie, and browsing the internet (shopping)
Discomfort after activity	Write down activities that were uncomfortable when performed in an autonomous vehicle experimental environment
Ideas for spatial design	Create a spatial design idea based on your in-vehicle activity experience
Preferred display position	Choose a preferred location for a display and explain the reason based on your experience in the experimental environment

In this study, a fully autonomous vehicle was defined as level four or five on the automation scale used by the Society of Automotive Engineering. In the concept of autonomous vehicles proposed for the near future, the interior design has the front passenger seat and the rear seats facing each other, although the driver's seat does not swivel 180° (Table 1). Therefore, this study focuses on in-vehicle activities in which occupants in the front and rear passenger seats engage in face-to-face communication and personal activities while the driver is driving. The results may be the basis for understanding the context of in-vehicle activities that include the driver's seat in the future. After setting this scope for the study, an experimental mock-up environment was created, and the SUV class of vehicles, which has been used for many concept cars and is being developed as a future autonomous vehicle size by automobile manufacturers, was selected for the size of the mock-up. The experiment's setting was created using the dimensions of a Kia Motors Carnival SUV interior so that the participants would experience the actual space that autonomous vehicles are initially likely to have (Table 4 and Figures 1 and 2).

We applied the size of the SUV class to the experimental mock-up. SUV class is widely considered by automotive OEMs as autonomous vehicles. The experiment's setting was created using the dimensions of a Kia Motors Carnival SUV interior so that the participants would experience the actual space that autonomous vehicles are initially likely to have. Since 2016, the concept of autonomous vehicles has been actively appearing, automobile manufacturers have introduced flexible layout for SUV and purpose-built vehicle (PBV), which is a box-type and modular architecture that is larger than the size of the SUV class (Table 1). If the existing indoor space of an SUV with more than 7 seats is applied to an autonomous vehicle, it is difficult to design the flexible layout required to support in-vehicle activities to an autonomous vehicle. For uses such as the swiveling function of the seat, the reclining function of a seat that can be used by expanding legroom, and the function of watching a video at distance considering the field of view, it is required to remove the third-row seats or to minimize the usability of it. For this reason, concept cars are mainly presented with less than 4 seats. In particular, automobile manufacturers are considering the layout of indoor space according to various use cases by using swivel seats. When swiveling the seat, there is interference between the seat and other spatial components. Various methods are being studied for a flexible layout mechanism that can minimize interference and passengers' discomfort. In addition, unlike existing vehicles, sufficient legroom must be created when using a reclining seat with leg rest function, and the situation in which the front and rear passengers simultaneously engage in in-vehicle activities such as sleeping requiring wide legroom and headroom is also considered. From the standpoint that autonomous vehicles are living space, it is considered an important factor to create a comfortable atmosphere in indoor space by reducing the number of seats to increase the sense of space for the passengers' comfort [31].

Table 4. Spatial components and experimental environment of fully autonomous vehicles (refer to concept car and consumer studies).

Spatial Components		Functions Applied to the Experimental Environment	Symbol Notation
Floor	Wood floor	Comfortable atmosphere	-
Relax seat	Relax seat in the front seat and rear seat	Sliding back and forth, Relaxing posture	A/B/C
Personal display/table	Touch display cum table	Sliding back and forth, Position adjustment	D
	Laptop cum table	Sliding back and forth, Position adjustment	E
	Table	Sliding back and forth, Position adjustment	F
Common display	Ceiling displays	Fixed position	G
	Dashboard display	Fixed position	H
	Display applied to the rear of the indoor space	Fixed position	I
Center console	Moving console	Sliding back and forth, Storage space	J
	Phone holder	Sliding back and forth, Position adjustment	K
Windshield (Road driving video)	-	Creating a virtual autonomous driving environment	L

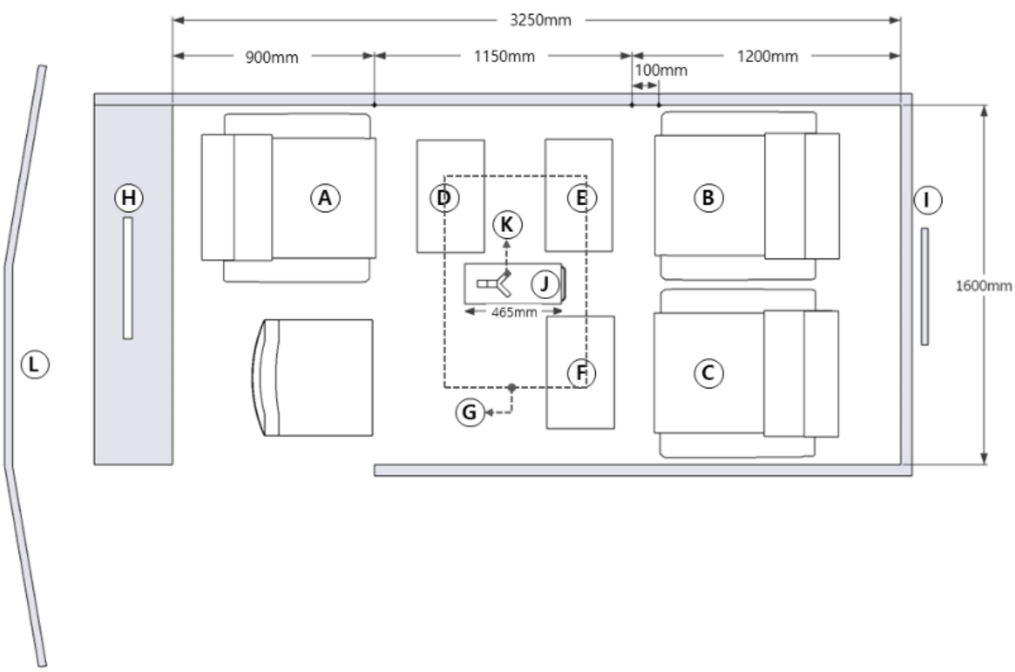


Figure 1. Layout of experiment environment of a fully autonomous vehicle.

Figure 2. Experimental design of the interior environment of a fully autonomous vehicle.

This study can be used to design smaller vehicles. In many cases, automotive OEMs design large vehicles and then apply them to smaller vehicles. Flexible layout is also being introduced in sedan and micro vehicle concepts (Table 5). The sedan concept is being announced as an indoor space that supports in-vehicle activities included in the results of this study. Therefore, a sedan has a similar interior design to an SUV. However, since the sedan's indoor space is smaller than an SUV, there is a tendency to intensively design the more important seats of the front or rear seats depending on the level of autonomous driving or the characteristics of passengers or reduce the functions that can be used by passengers [16,31–33]. As another method, the sedan concept of improving space utilization by reducing the number of seats is also being proposed like some SUV concepts [34]. There are few cases in which the swivel seat or reclining seat is applied to a micro vehicle. However, it is possible to use the passengers' behavior and requirements about conversations with the passenger in the same row, eating meals and snacks, inaction, activities that use a table, watching a video, and using a cell phone included in the results of this study [35–38]. The flexible layout presented in this study is the result of approaching the relationship between in-vehicle activities and spatial components and design elements in terms of context, so it can be used to various vehicle sizes. It is important to find out the physical dimensions required for spatial design for each vehicle class.

3.2. Analysis

Since this study conducted qualitative research with a small number of subjects, the experiment was designed to increase the reliability and validity of the study. We conducted a qualitative study using a multifaceted usability testing method, and methodological triangulation was performed to avoid a biased interpretation of the results and ensure validity and accuracy in observers' judgments. Triangulation is a method that re-examines the interpretation of data by varying the viewpoint, time, space, and situation of the study to increase reliability and validity [39–41] Among them, methodological triangulation is widely used as a method of examining phenomena using multiple research methods.

Data obtained through the video observation method were used to analyze the relationship between participants' actions and the setting using the AEIOU framework. It is necessary to define what the term "activity" covers in the AEIOU framework to set a clear standard for analyzing detailed interrelationships. Accordingly, in this study, our analysis was conducted based on the hierarchical structure of "activity, action, and operation" within the activity theory that has been used as a theoretical basis for analyzing and utilizing contextual information. An "activity" is composed of a series of actions, and an "action" is composed of a series of operations [42]. An "activity" is oriented by an "object," an "action" is structured as a conscious and concrete "goal," and an "operation" is a method of realizing an "action". Based on the AEIOU framework and Activity Theory, intra-rater reliability was conducted to ensure reliability when analyzing the relationship between a participant's action and the environment. As a result of conducting video analysis on units of action twice every 6 months, the reliability was found to be 96.94%.

Table 5. Spatial components by vehicle classification (●: many cases of a concept car, •: several cases of a concept car, ○: few cases of concept car).

Vehicle Classification		Seat			Table		Display		Center Console	Floor
		Relax	**Swivel (180°)**	**Swivel (Less than 90°)**	**Personal**	**Common**	**Personal**	**Common**	**Moving Console**	**Comfortable Atmosphere**
Micro	Front seat	○	○	○	•	○	○	•	○	•
	Rear seat	○	○	○	○	○	○	○		
Sedan	Front seat	•	○	•	•	○	○	•	○	●
	Rear seat	•	○	○	•	○	•	○		
SUV	Front seat	●	●	•	•	•	•	•	•	●
	Rear seat	●	○	○	•	•	•	•		

3.3. Participants

We conducted experiments on three participants who were aware of the changing concept of autonomous vehicles. Sample size issue has been discussed in both quantitative and qualitative studies. However, qualitative research does not necessarily increase the power of the test by increasing the sample size. The researcher should not determine the required sample size in advance but should evaluate whether the sample size is appropriate during analysis [43]. Since the aim of qualitative research is not an in-depth exploration of a subject, it is important to use a sampling method that can explain the subject well and to show suitability through specific descriptions of the sample [43]. According to Nielsen's research, which is widely referenced in the user experience field, even 3 users are enough to get insight and idea into what can be generalized [44]. This study aimed to understand the relationship between behaviors and components in the context of flexible layout design and targeting subjects who are aware of the changing spatial design concept because autonomous vehicles of level 4 or higher were not commercialized. Participation was limited to subjects with more than one year of experience in future mobility research. These participants are more familiar with the use of various components in a vehicle than people with no background in mobility research, even if they have no experience in an actual autonomous vehicle. The participants are aware of the changing concept of spatial design for autonomous vehicles and are more familiar with the use of various components in a vehicle than people with no background in mobility research, even if they have no experience in an actual autonomous vehicle. In the experiment, in-vehicle activities representatively presented in the concept car were included, and the relationship between all spatial components in Table 4 and the activities was analyzed. Therefore, even without targeting a large number of subjects, design elements to be considered in the flexible layout were identified. The selection of participants was conducted using purposeful sampling. This technique is included in non-probability sampling techniques and is commonly used in qualitative research.

We constructed a mock-up setting with an interior space that can accommodate four people, in which the front and rear passenger seats face each other, although the driver's seat does not swivel 180°. The empirical study constitutes an important part of design research, thereby discovering essential insights while supporting theory-building [45,46] and the assessment of real-world impact [46,47]. Small-scale studies can provide insights into design issues in a laboratory setting, whereas quantitative research does not sufficiently capture the multifaceted nature of human experience and the details of that experience in a generalized structure [46]. Therefore, this study, which aims to understand behavior in terms of a specific context, can capture the essence of that experience based on observation.

4. Results

To analyze the user experience in the context of the interior spatial design of an autonomous vehicle, it is necessary to create a space that allows variable spatial components to be used efficiently. For this investigation, sleeping and reclining, face-to-face conversation, watching videos, and browsing the internet (shopping) were selected as the participants' preferred in-vehicle activities. In addition, a sliding center console and options for designs in variable spaces were added, and hence, the activity of eating snacks contained in the center console was included as an additional task to understand how vehicle occupants would use the sliding center console. In addition, creating a questionnaire was included as a task so that we could observe how the participants used the design element of the table and the issues that came to mind for the participants during the experiment could be recorded immediately. There are six types of interior space arrangements in the "environments" section, and 11 in the "interactions" section (Table 6). In addition, through observation and analysis, seven activities were identified according to the definition of "activities" based on the AEIOU framework. These "activities" are sleeping and reclining, face-to-face conversation (listening/speaking), table-use activities (work), eating snacks, watching videos, and other postures (inaction-basic sitting posture and posture change).

There were 27 types of "action" units according to the activity theory (Figure 3 and Tables 7 and 8). Observers analyzed "environments," "interactions," "objects," and "users" for each "action" unit. The ratio of the frequency of "action X" to the total number across all "actions" and the ratio of time spent doing that "action X" relative to the entire time spent in the setting were computed, and the concurrent "action" units in which one participant performed various activities at the same time were also analyzed. Actions can be analyzed in terms of the total number of occurrences, the frequency (number of occurrences for a given period), intensity (force and magnitude of action), or duration (how long the action lasted) [48], and it is possible to collect objective and relatively accurate information with which to measure frequency and duration through observation [49,50].

In this experiment, for sleeping and reclining activities, using the reclining function (including the case of interference between the seat and other elements), restoring the seat position due to interference between the reclining seat and the table, returning the seat position, moving the table forward to use the reclining function (creation of personal space), moving the center console forward to use the reclining function (creation of personal space), and moving the seat backward to use the reclining function (creation of personal space) were defined as units of action. Among them, the frequency of use of the reclining seat was 9.21% and the ratio of duration to action was 38.09%, showing that the ratio of the frequency and the ratio of the duration were both among the top three rankings. Sleeping and reclining activities are representative of in-vehicle activities that automobile manufacturers are pursuing in future vehicle concepts. According to studies conducted in South Korea, consumer preferences for sleeping and activities related to reclining tended to be high, and preferences for work, reading, and other productive activities were shown to be relatively low. However, in other studies that used a survey regarding preferences for activities in a fully autonomous vehicle, productive activities such as work and reading were ranked more highly than sleeping and activities related to reclining. According to Pfleging et al., out of the 300 respondents to a survey in Germany, only 32.7% expected to sleep, and most had high expectations for activities such as talking to another passenger or listening to music or the radio [21]. In research conducted on consumers in other countries such as the U.K., Australia, China, the U.S, Japan, and India, the preference for activities such as reading, talking to acquaintances on cell phones, and work was higher than for sleeping and activities related to reclining [51,52]. As such, consumers' preferences for in-vehicle activities appear to vary by country, and thus, it is necessary to consider and present design elements according to country-specific consumer characteristics and needs when designing the space of an autonomous vehicle.

When the reclining seat and the table interfere, subjects took the action of pushing the table away from the seat by placing the reclining seat in its original position. When the reclining seat interfered with the center console, the action of creating personal space by moving the center console away from the seat was observed. In addition, it was observed that sleeping and reclining activities were done in a way that created personal space by sliding the reclining seat backward. A design that allows for creating personal space in the limited interior space of the vehicle should be considered, such as when the front and rear passengers use reclining seats at the same time. In general, an understanding of how the different spatial components can interfere with each other should be considered as an essential design factor.

In addition, participants engaged in several activities while using the reclining seat function, such as talking with another passenger, watching videos, or using a cell phone. These action patterns, which should influence design decisions, were not considered in previous studies. In an autonomous vehicle, the occupants do not only pursue one activity at a time; the activities and actions of individual occupants are simultaneous and complex. It is necessary to create design elements based on an understanding of these complex actions based on a contextual understanding that captures the relationship between activities, actions, and spatial components.

In face-to-face conversation (listening/speaking) activities, i.e., talking with another passenger (changing one's posture to look at the other person), talking with another passenger while using the table (working), talking with another passenger while using the seat's reclining function and returning the seat to its original position, talking with another passenger while returning the seat to its original position because of interference between the seat and the center console or table, talking with another passenger while using a cell phone, leaning over and talking to another passenger while taking snacks from the center console, talking with another passenger while moving the table, and talking with another passenger while using the center console, were counted as units of action. Among them, the frequency ratio of conversations with another passenger was 7.89%, which was within the top three actions in terms of total frequency. This aspect includes the situation in which one participant changed his or her position looking at the other passenger. Therefore, it is necessary to consider the seat arrangement and seat swivel angle to accommodate the passengers' preferred posture. In a study by Ive et al., both participants wanted to turn their heads instead of transforming the interior space to look at the passengers, as well as those who wanted to be able to swivel the seat [23]. In a study by Pettersson, several swivel seats were proposed, thereby expressing the interest that participants had for the new, more social interior design opportunities that could be possible with autonomous vehicles [9]. In addition, many related concepts such as swivel seats for each seating position or moving the center console around the seats are being introduced such as in Adient's AI17, Hyundai Transys' 1st generation autonomous driving seat, and Nissan's IDS [53–55]. According to the preferred seat arrangement pattern shown in this experiment and previous research, the seat arrangement and seat swivel angle can be determined according to factors such as the number of passengers and seating positions of passengers. In other words, it is necessary to consider the seat arrangement and the seat swivel angle according to the situation and the overall design factors.

Table 6. Arrangements of indoor space of an autonomous vehicle.

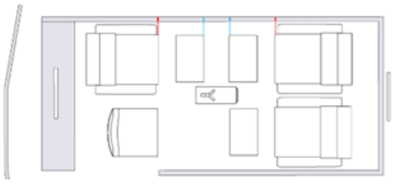
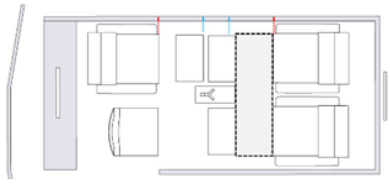
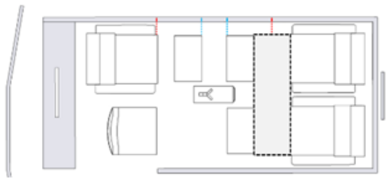
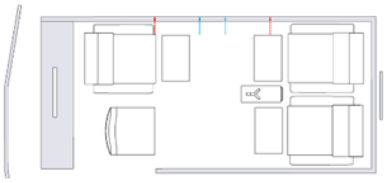
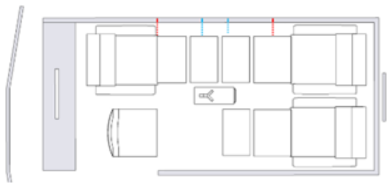
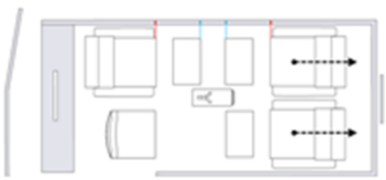
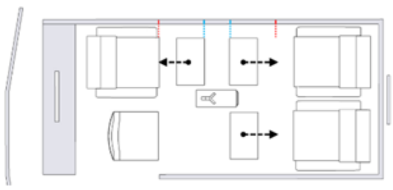
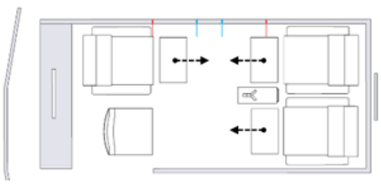
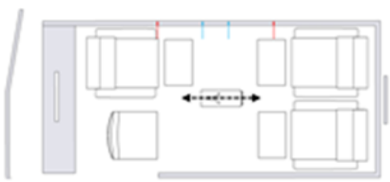
Classification	Arrangement of Indoor Space	
Environments	(a) Basic indoor space 	(b) Creation of personal space by moving tables and moving the center console 
	(c) Creation of personal space by moving the seat 	(d) Creation of personal space by moving tables (where the console is located close to the seat like a table) 
	(e) Placing the table and moving the center console close to the seat (in the case of the center console, place it close to the seat only for related activities) 	(f) Uses reclining seats 
Interactions	(1) Moving the seat to the rear 	(2) Moving the table to the individual passenger (the initial seat position and after the seat is moved) 
	(3) Moving the table away from the individual seat (the initial seat position and after seat movement) 	(4) Moving center console 

Table 6. *Cont.*

Classification	Arrangement of Indoor Space	
	(5) Initial seating position	(6) Changing the seating posture (sitting with legs on the seat, using a table, looking at other passengers, bending back, etc.)
	(7) Operating, using, returning the reclining seat function	(8) Opening and using the storage space of the center console
	(9) Using the personal table and display	(10) Watching videos
	(11) Using and placing cell phone on a table	

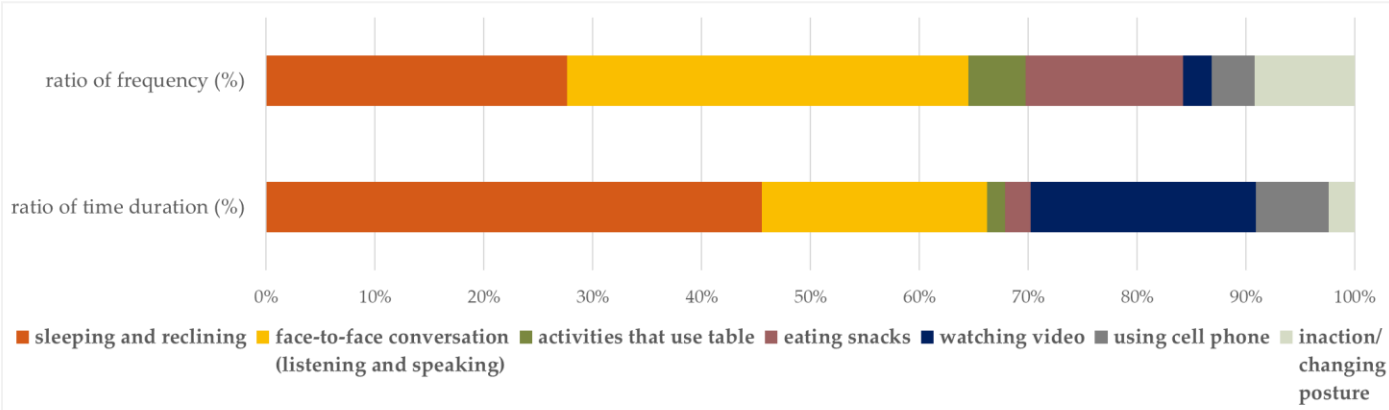


Figure 3. Ratio of frequency and time duration.

In addition to simply talking with other passengers, the ratio of the frequency of conversation with other passengers while using the table (such as for doing work) was 13.16% and the ratio of the duration was 6.45%, showing that both the overall frequency and the duration were ranked in the top three. Similarly, there were several other actions that involved multiple activities at the same time as having a conversation, including sleeping and reclining, eating snacks, and using cell phones. If only two passengers participate in the conversation, the activities of other passengers may be affected. Not all passengers prefer face-to-face seating arrangements. Therefore, it is necessary to apply a face-to-face seating arrangement to an autonomous vehicle for a specific purpose, or in the case of a flexible face-to-face seating arrangement. In addition, in the case of a fixed face-to-face seating arrangement, the design should accommodate individual activities.

During table-use activities (work), if the distance between the seat and the table was large, participants changed the table position and the table angle to make using the table more comfortable. It was observed that when using the table to perform activities such as work, participants did not maintain their basic seating posture but leaned toward the table to make it easier to use and then returned to their basic seating posture. There is an expectation of and preference for productive activities that include the use of the tables or laptops, such as work and reading, in a fully autonomous vehicle in the future. Therefore, seats should be designed based on research related to user actions and postures in their daily living and workspaces. In addition, a comprehensive design plan that considers the shape and position of the table, and the gap and height difference between the seat and the table should be developed.

Table 7. Analysis of "action" unit characteristics by "activity" unit ([1] ratio of frequency (%), [2] ratio of time duration (%), [3] the number of activities that took place concurrently, [4] in the case of table-use activity, the task of completing the questionnaire is performed, and thus, it is excluded from the analysis of the ratio of frequency and ratio of duration).

A			E/I						O	U			Frequency (%) [1]	Duration (%) [2]	Activities [3]
Activity		**Action Unit**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**		**A**	**B**	**C**			
Sleeping and reclining	1	Using the reclining function (including the case of interference between the seat and other elements)	(7)	(7)	(7)	(7)			A, B, C	O	O	O	9.21	38.09	9, 22, 25
	2	Restoring the seat position due to interference between the reclining seat and the table						(7)	A, D	O		O	2.63	1.91	10
	3	Returning the seat position						(7)	B, C		O	O	5.26	1.58	9
	4	Moving the table forward to use the reclining function (creation of personal space)	(3)					(3)	E, F		O	O	3.95	2.11	13
	5	Moving the center console forward to use the reclining function (creation of personal space)	(4), (6)			(7)			J			O	2.63	0.72	-
	6	Moving the seat backward to use the reclining function (creation of personal space)	(1)	(1)	(1)				B, C	O	O	O	3.95	1.12	-
Face-to-face conversation (listening and speaking)	7	Conversation with a passenger (changing posture to look at the person)	(5)					(5), (6)	A, B	O	O	O	7.89	6.05	-
	8	Conversation with a passenger while using the table (work)					(6), (9)		A, B, C	O	O	O	13.16	6.45	15.16
	9	Conversation with a passenger while reclining the seat and returning to the original position						(7)	A, C	O		O	5.26	3.09	1.3
	10	Conversation with a passenger while returning the reclined seat to its original position because of the interference between the seat and center console or table						(7)	A, C, D	O		O	2.63	1.18	2
	11	Conversation with a passenger while using a cell phone					(5)		B		O		1.32	1.78	24
	12	Bending over and talking to a passenger while taking snacks from the center console					(6), (8)		B, I	O	O	O	1.32	0.26	17

Table 7. *Cont.*

A			E/I						O	U			Frequency (%) (1)	Duration (%) (2)	Activities (3)
Activity		**Action Unit**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**		**A**	**B**	**C**			
	13	Conversation with a passenger while moving the table	(3)				(3)		E, F	O	O	O	3.95	0.92	4
	14	Conversation with a passenger while using the center console and back					(5)		C, J	O	O	O	1.32	0.92	21
Activities that use table	15	Checking and filling out the questionnaire (4)							-						
	16	Changing the position and angle of the table	(2)		(2)	(3)			D, E, F	O	O	O	5.26	1.71	8
Eating snacks	17	Taking a snack out of the center console				(6), (8)	(6), (8)		B, C		O	O	5.26	0.79	12
	18	Handing or receiving snacks to another passenger					(6)		A, C	O	O	O	3.95	0.72	-
	19	Changing the position of the table to use the center console					(3)		E		O		1.32	0.26	-
	20	Changing the position of the center console for ease of use				(4)	(4)		J		O	O	2.63	0.13	-
	21	Putting the console back in place					(6), (8)		C, J			O	1.32	0.39	14
Watching videos	22	Watching the video from the ceiling display when relaxing on the reclined seat					(10)		G		O	O	2.63	20.72	1
Using a cell phone	23	Using and placing a cell phone on the passenger's leg					(11)		A, B	O	O		1.32	2.96	-
	24	Using and placing a cell phone on the table					(11)		B		O		1.32	3.22	11
	25	Using and placing a cell phone on the body when in reclining seat					(11)		C			O	1.32	0.46	1
Inaction/ Changing Posture	26	Basic sitting posture without in-vehicle activities			(5)		(5)		B		O		5.26	0.86	-
	27	Change of posture (cross-legged/putting feet on the seat)					(6)		C			O	3.95	1.58	-

Table 8. Activities and Actions.

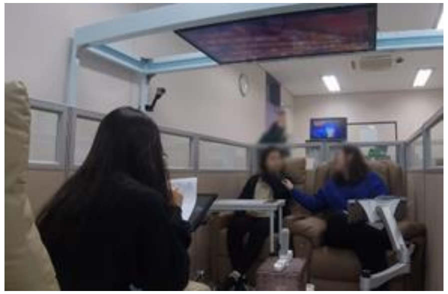
Activities	Image	Activities	Image
Sleeping and reclining	 Creation of personal space by moving tables and moving the center console to use the reclined seat	Face-to-face conversation (listening and speaking)	 Conversation with another passenger (changing posture to look at the person)/simultaneous occurrence of activities
Activities that use table	 Changing the seating posture to use the table after changing the table position and angle	Eating snacks	 Leaning toward the center console and taking out a snack, after participants place the center console close to them

Table 8. *Cont.*

Activities	Image	Activities	Image
Watching videos	 Watching the video from the ceiling from a reclined seat	Using a cell phone	 Using and resting a cell phone on the body when in the reclined seat
Inaction/ Change posture	 sitting cross-legged		

Eating snacks, taking snacks out of the center console, handing or receiving snacks to other passengers, changing the position of the table to use the center console, changing the position of the center console, and putting the console back in place were identified as units of action. When the center console was moved to one side, a participant whose relative distance was closer to the storage space in the center console took out a snack and handed it to the passenger on the opposite side. Through this action, we determine that when the storage space is available to only one side of the moving center console, the other passenger is not able to conveniently use the functions assigned to the moving center console because of the distance to the storage space. Situations in which the movable center console is used by front and rear passengers individually or together should be considered separately.

In the case of the activity "watching videos," watching from the ceiling display when reclining were labeled as units of action, and the ratio of duration was 20.72%, which was ranked second overall. Rather than using a personal display to watch a video, there was a tendency to watch videos through a large display applied to the ceiling, along with the action of taking a break while using the reclining seat function. As the range of positions that passengers can adopt in an autonomous vehicle is expected to expand, it is important to consider the location, size, shape, and usage of the video display monitor. Automobile manufacturers, related IT companies, and display manufacturers predict that the importance of activities involving displays will increase, and research and development are actively underway to incorporate new technologies related to display, including size, shape, and location. Byton, an automobile manufacturer in China, installed a 48-inch display on the dashboard to provide the driver with various types of information such as navigation, air conditioning controls, and infotainment options [32]. A BMW Inside Future Concept car applied a ceiling display for the rear seat so that passengers could enjoy entertainment activities [56]. Panasonic introduced a 77-inch ceiling display and a 55-inch door trim display, suggesting a new direction for passengers to use various types of content through the display [57]. The use of displays in vehicles is predicted to increase, as is display size, and the locations where displays are installed will be expanded. Therefore, it is necessary to consider the design elements of the display by incorporating all of the user's actions, posture, and user preferences.

In the case of using cell phones, using and resting a cell phone on a passenger's leg, using and mounting a cell phone on a table, and using and resting a cell phone on the body while in a reclined seat were identified as units of action. It was observed that the cell phone was always placed in a position that the participant's hand could easily reach, regardless of the participant's posture or activity. In addition, even when taking a break using the reclining seat function, the action of using a cell phone in a lying down position was observed, and the action of using a cell phone was consistently observed when participants performed in-vehicle activities other than resting. In previous studies, contacting others via cell phones was found to be a preferred activity in autonomous vehicles [51,52]. This aspect shows that understanding design elements such as the location and shape of cell phone holders to improve the convenience of using a phone in various postures is important.

In the case of inactivity and changing postures, sitting in a basic sitting posture without doing any other activities, and changing posture (sitting cross-legged and putting passenger's feet on the seat) were identified as units of action. Such actions were observed in this experiment, and previous studies that investigated preferred activities in autonomous vehicles indicated that a high percentage of respondents would stare at the road or do nothing instead of engaging in specific activities. Therefore, it is necessary to consider not only interior designs presented in the context of in-vehicle activities but also the spatial design in a state in which passengers do not perform any activity when riding in an autonomous vehicle. It is also necessary to design the seat by considering the basic seated posture of everyday life. Based on the AEIOU framework, the design elements to be considered are organized by determining the relationship between the interior environment and actions (Figure 4).

It is necessary to consider design factors for each spatial component by combining the subjective opinions of participants experiencing the interior space of a virtual autonomous vehicle with an analysis of actual actions to understand the context. In this study, design considerations for each component of an autonomous vehicle interior were derived from an in-depth and multifaceted approach using observation, surveys, and think-aloud research methods. The survey has the advantage of obtaining data that converge on the research purpose within a predictable range. The think-aloud method compensates for the shortcomings of the questionnaire survey, which does not provide a wealth of information about the subject's thoughts regarding the experience. This study attempted to comprehensively collect subjective opinions using a questionnaire survey and the think-aloud method. Based on this, and the contextual understanding identified through observation and a survey; the problems and experiences for each in-vehicle activity was obtained for each spatial component of the vehicle mock-up (Table 9). In this study, we suggest the direction of design elements for each in-vehicle activity, i.e., sleeping and reclining, face-to-face conversation, watching videos, and personal work (Table 10).

According to the results of this study, various activities and actions can occur in face-to-face seating arrangements. When four seats with reclining function were applied to the SUV class mock-up, it was found that spatial components interfere with each other during in-vehicle activities. When applying a seat arrangement of five or more seats in an SUV class, it is necessary to check whether the legroom, headroom, and shoulder room are designed so as not to be inconvenient when using the functions applied to each seat.

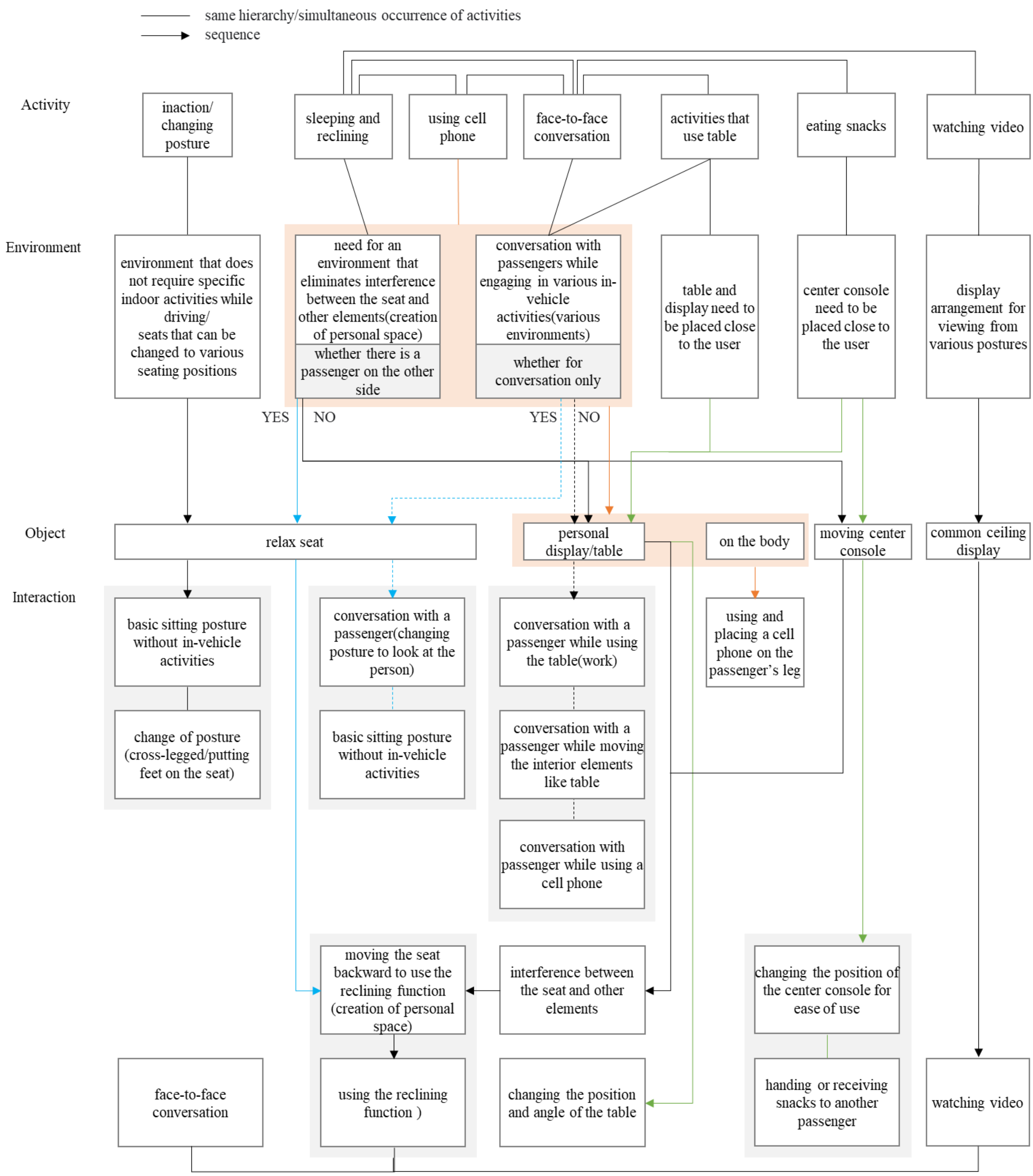


Figure 4. Indoor environment relationship and design elements through analysis of action.

Table 9. Design considerations for each spatial component.

Spatial Component			Problems and Phenomenon	AEIOU	Survey	Think-aloud
Relax Seat	Relax seat in the front seat	Face-to-face conversation	The participant wants the seat to swivel to 90 degrees or less, not 180 degrees.		O	
			Participants perform different activities at the same time.	O		O
			The fixed face-to-face seating arrangement makes participants feel like they have to continue talking with passengers.	O		O
		Sleeping and reclining	Seat shape adjustment function is required.		O	
			Bedclothes, massage function, and neck fixing function are required.		O	
			The participant feels anxious when they returned to the basic upright seating posture after being in the reclined posture for a while.		O	
			Participant needs a stable feeling for the reclined seat posture.		O	
			It is inconvenient to operate because it takes a long time to use the reclining mode function.			O
	All seat		The seat position is adjusted by the participants to create personal space for use in the reclined mode.	O		
		Sleeping and reclining/ Face-to-face conversation	The function to change the armrest position is needed.		O	
		Face-to-face conversation	It is uncomfortable to be unable to face the passenger in the adjacent seat.		O	O
			When handing an object to a passenger on the other side, the individual bends at the waist with arms extended.	O		
		Face-to-face conversation/work	Participant changes from the basic sitting posture to a posture with legs on the seat.	O		
		Inaction	There is a situation that participants do not engage in in-vehicle activities.	O		
Indoor light and sound environment	Light/ Window	Sleeping and relaxation	The participant feels uncomfortable with sunlight or lighting.		O	
			Reduced lighting for a sleeping mode is needed.		O	
	Soundproofing	Sleeping and reclining	It is necessary to reduce noise.	O	O	O
			Activities occur simultaneously (when passenger B and passenger C talk together, passenger A takes a break and performs other activities such as work).	O	O	O
		Face-to-face conversation	The participant feels it is noisy when other passengers are talking.			O
			The participant feels obligated to talk to other passengers because of the fixed face-to-face seating arrangement.			O

Table 9. *Cont.*

Spatial Component			Problems and Phenomenon	AEIOU	Survey	Think-aloud
Personal display/Table	Table	Watching video	Participant needs personal display.		O	
		Work	It is inconvenient to manually adjust the table position.		O	
		Face-to-face conversation	Participant refers to a centrally located common table.			O
		Any situation	When using a reclined seat after using a personal display or table, there is a problem of interference between the seat and the personal display or table.	O		
		Sleeping and reclining	Spatial components (table) used for sleep and rest are positioned so that they do not interfere with the seat.	O		
	Display	Any situation	Participant prefers the display to be located close by while performing activities such as browsing the internet and work.		O	
Common display	Ceiling Display	Watching video	It is uncomfortable to watch the video because the front and rear passengers cannot look in the same direction (it is difficult for passengers in one of the front and rear seats to watch the video).	O	O	O
			Participant prefers ceiling display in reclined mode.	O	O	O
			Complex activities such as resting and watching a video occur.	O	O	O
			The large display size makes it easy to enjoy and watch a video with other passengers.		O	
	Dashboard display	watching video	When seated toward the front of the vehicle, it is preferred to install the display on the dashboard part of the vehicle.		O	
			Participant prefers the dashboard display position while driving.		O	
	Display applied to the rear of the indoor space	watching video	The passenger in the passenger seat wants to sit facing the front and watch the display rather than watching the video in a face-to-face seating arrangement.		O	
Center Console/Storage space	Moving center console phone holder	Using storage space	When features such as storage space are in one part of the moving center console, it is difficult for passengers in both the front and rear seats to use them.	O		
		Using cell phone	During rest or in-vehicle activities using a table, if a cell phone holder is not provided for each individual, the participant places the phone on the body or uses the table.	O	O	O
			The participant feels that it would be better to hold the cell phone in their hand if it shakes while driving.	O	O	O
			A device to hold the cell phone is needed.	O	O	O
			The participant is worried that motion sickness will occur when using a cell phone while driving.		O	

Table 10. Direction of space design elements by in-vehicle activity.

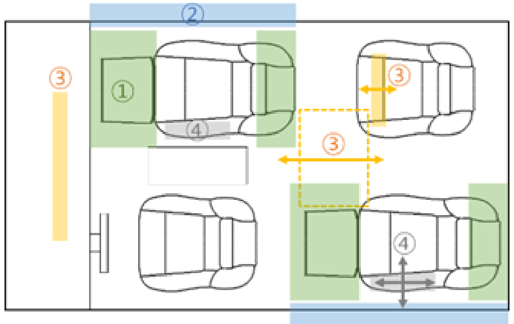
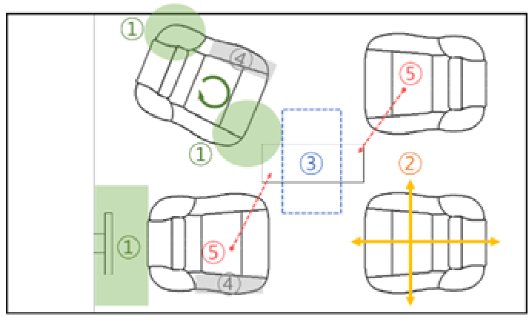
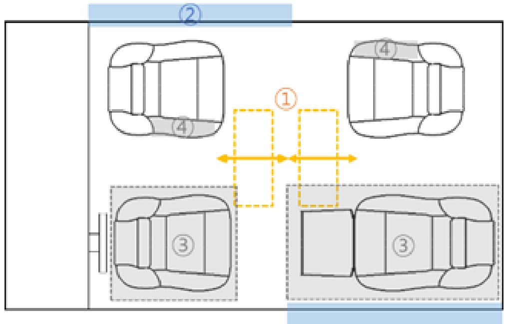
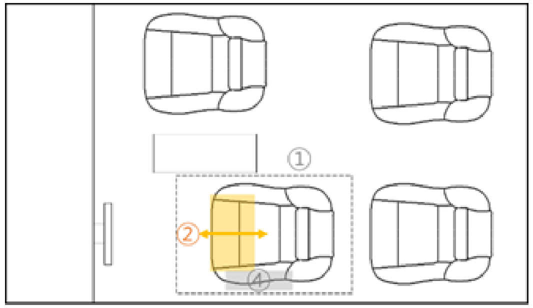
Classification	Direction of Space Design Elements	
	1. Sleeping and reclining	**2. Face-to-face conversation**
Space arrangement		
Seat	Creation of space in front of and behind the seat and creation of sufficient distance between the seat and its surrounding elements (①). Function to adjust the seat shape such as headrest and armrest.Seat with a sense of stability in a relaxed posture.	Ability to freely adjust the swivel angle of the front and rear seats (located by identifying the factors that interfere with the seats) (①). Seat front, rear, left, and right sliding function considering situations such as exchanging goods between passengers (②).
Indoor light and sound environment	Sun protection window to prevent light from entering when sleeping/Atmosphere in sleep mode (②).Soundproofing device that can reduce ambient noise for each individual seat	Soundproofing device that can reduce ambient noise for each individual seat.
Display	When changing to a relaxed posture, creating a distance from the personal display (creating personal space). Position adjustment function to be able to use personal or common display after changing to a relaxed posture (③).	-
Table	When changing to a relaxed posture, creating a distance from a personal table (creating personal space).	Common table for sharing things (③).
Center console/Storage space	Personal cell phone holder that can be positioned and angled for use in any posture (or is integrated with the table and display) (④).	Personal cell phone holder that can be adjusted in position and angle for use in all postures (④).Console: A function applied to both ends of the console so that both front and rear passengers can use it/or a function to change the location so that storage can be used in all seats (including when driving from the driver's seat) (⑤).

Table 10. *Cont.*

Classification	Direction of Space Design Elements	
	3. Watching videos (including posture during sleeping and reclining)	**4. Personal work**
Space arrangement		
Seat	As video is sometimes watched in a relaxedposture, seat adjustment function, and display distance and angle adjustment function (①).	Seat shape adjustment function for a comfortable working position.The seat belt function according to the seating posture.
Indoor light and sound environment	Sun protection window (②).A sound function that does not transmit noise to the surroundings (③).	Lighting and atmosphere suitable for work considering the evening after sunset.Environment not disturbed by surrounding noise (①).
Display	Personal display with adjustable position and angle. Position change function to allow viewing of a common display in all seats (front of dashboard or ceiling display in both directions) (①).	-
Table	-	Personal table (②). Table adjusted according to seat position (②).
Center console/Storage space	Personal cell phone holder that can be positioned and angled for use in any posture (④).	Personal cell phone holder that can be positioned and angled for use in any posture (④).

Since the scope of the autonomous vehicle in this study was a fully autonomous vehicle with level 4 or higher, the study was conducted under the assumption that physical environmental factors affecting in-vehicle activities will be resolved in future city and mobility environments. Physical environmental factors affecting in-vehicle activities include safe driving (i.e., rapid deceleration and acceleration, sudden lane changes and non-compliance with safety distance), safety device (i.e., seat belts and airbags), motion sickness, noise generated between passengers, noise from the vehicle and external environment, and interference from sunlight. According to the definition of the autonomous vehicle as a comfortable living space, technology is being developed in both technical and spatial aspects to solve the problems of these physical environmental factors. Automobile manufacturers are developing technologies to solve situations such as rapid deceleration and acceleration, sudden lane change, and non-compliance with safety distance for the development of fully autonomous vehicles [19]. In the development of safety devices such as seat belts and airbags, automobile manufacturers such as Volvo and previous studies have considered and developed a seat belt system that can protect passengers in consideration of changes in seat position and passenger posture [58–60]. Volvo has developed a system that informs passengers when it is safe to unfasten the seat belt in a future autonomous vehicle. In addition, Volvo developed safety blankets to act like seat belts. These blankets can usually cover the body loosely, and in case of an emergency, the seat belts are automatically tightened to protect passengers [59,60]. Companies like airbag supplier Autoliv create a design to accommodate face-to-face seating configurations and swivel seats for autonomous vehicles [61]. In face-to-face seating arrangements, airbags are being developed to be placed on the ceiling, door trim, and seat. According to a research report from Michigan University, the frequency and severity of motion sickness will be affected by in-vehicle activities [62]. To reduce motion sickness, studies are being conducted not only in the technical aspect but also in the spatial design aspect. Daimler Benz conducted a study on the effect of reducing motion sickness according to the seatback angle by understanding the relationship between passenger's posture and motion sickness [63]. Technology to reduce noise is also being developed, and Covestro has developed interior materials that can improve passengers' comfort and reduce noise [64].

Hyundai Motors has designed an indoor space to include both independent acoustic functions for individual passengers and the ability for passengers to talk at any time. Sun protection can become important depending on indoor activities, such as when sleeping or watching a movie. Kia Motors has developed a glass that blocks light by itself, and the light is blocked by considering the direction in which the passenger sits and the location of sunlight [65].

To solve the physical environmental factors affecting the activities, technology development and research are being conducted in terms of spatial design. The experimental results of this study also revealed concerns and requirements for discomfort due to sunlight, noise between passengers, and motion sickness (Table 8). Studies are needed on how to solve the problems of physical environmental factors in flexible layout in terms of technical and spatial design aspects. The considerations from the perspective of spatial design to solve problems caused by physical environmental factors are shown in Figure 5.

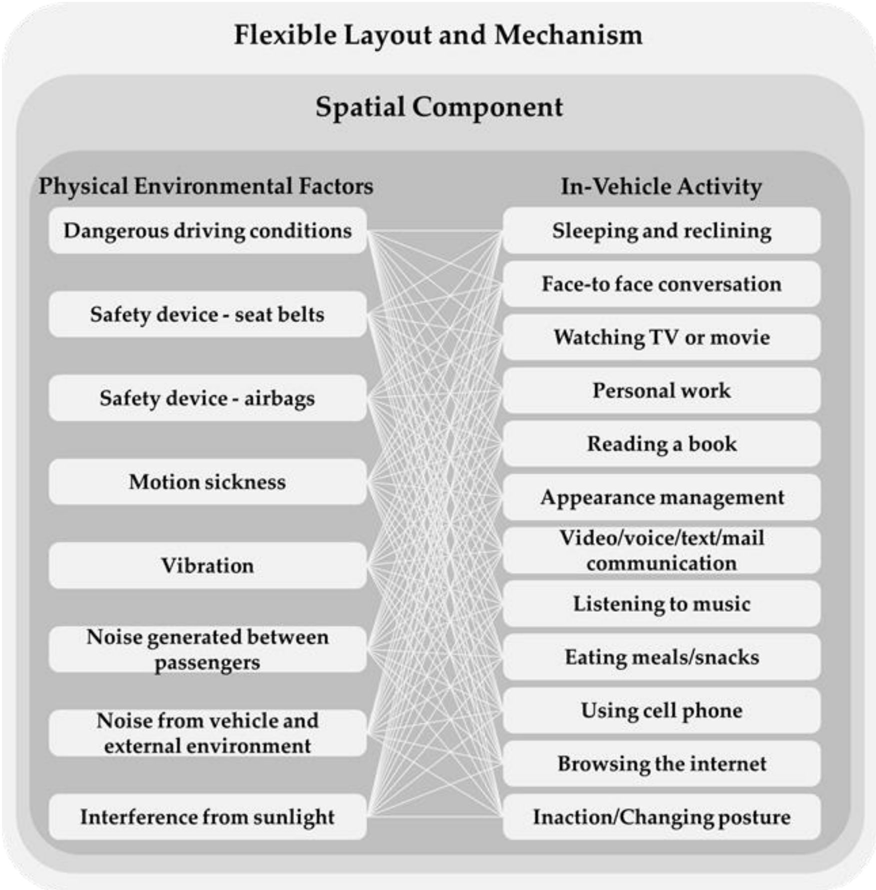


Figure 5. The considerations from the perspective of spatial design to solve problems caused by physical environmental factors.

5. Discussion

This study was conducted from the viewpoint of creating an interior space for autonomous vehicles, which are expected to be encountered in the near future, that focuses on the efficient use of that space from a user-centered perspective. Given that the interior of a vehicle constitutes a confined space, it is important to design a flexible layout in different aspects of the overall space. Therefore, this study aimed to analyze the relationships among various elements related to the use of space in a face-to-face seating arrangement of an autonomous vehicle. Unlike most of the previous spatial design studies that used actual traditional vehicles and driving simulators designed with a traditional vehicle interior, we used a mock-up that incorporates the flexible spatial design of an autonomous vehicle. Most of the flexible spatial design studies that used a mock-up did not consider the confined space of an autonomous vehicle. However, in this study, the experiment's setting was created using the dimensions of an SUV interior so that the participants would experience the actual space that autonomous vehicles are initially likely to have. Several studies related to hands-on experience have been conducted with a fragmented approach, focusing on individual elements. But this study uses the various spatial components suggested in a concept car to understand spatial design elements. In terms of methodology, we used the AEIOU framework to collect objective and relatively accurate information from observational data. In this respect, our study differs from previous studies. The conclusions based on the results of our analysis are presented below.

First, it is necessary to consider that various activities and actions can occur in a face-to-face seating arrangement. The fixed face-to-face seating arrangement makes participants feel like they have to continue talking with passengers. If only some passengers participate in the conversation, the activities of other passengers may be affected. As in many concept cars, where one can see the direction of future automotive space design, it is necessary to consider the environment and features required for each individual passenger, for each in-vehicle activity. It is important to recognize that face-to-face seating arrangements are not just to facilitate conversation but can be seen as an environment in which each passenger can conduct other in-vehicle activities individually. Second, in an autonomous vehicle, the passengers do not only pursue one activity at a time; the activities and actions of individual passengers are simultaneous and complex. It is necessary to create design elements based on an understanding of these complex actions based on a contextual understanding that captures the relationship between activities, actions, and spatial components. Third, unlike the basic seating posture assumed in existing vehicles, it becomes possible to take on a variety of postures of daily life in the interior space of an autonomous vehicle. Given that the passengers' range of motion can be expanded, consideration should be given to the passengers' positions within the context of various in-vehicle activities. As shown in many concept cars, the direction of future automotive space design should consider what features are required for each individual passenger to engage in each in-vehicle activity. Differences in spatial design elements may be required depending on the passenger's desired range of postures in an autonomous vehicle, such as lying down, and a seated posture where the passenger is leaning forward.

This study has certain limitations as the experiment was conducted using a mock-up, not an actual vehicle interior space. In subsequent studies, it will be important to test a reclined seat configuration in an actual vehicle or create an experimental environment that is quite similar to an actual vehicle. Details of various design factors such as the size and location of each component should be studied to make them convenient for the passengers within the confined interior space of a vehicle. While this study was aimed at not only analyzing passenger behaviors using specific features and functions and collecting opinions of participants regarding those features and functions, it also focused on allowing subjects to directly experience the interior space. However, this study is limited in that the degree of freedom the subjects had to adjust the spatial components was relatively low because the study was limited to a face-to-face seating arrangement. In a follow-up study, it will be important to observe and analyze passengers' activities and behaviors in variable spatial arrangements other than a face-to-face seating arrangement such as using a seat swivel function. To observe in-vehicle activities and behaviors, the scope of in-vehicle activities in this study was determined based on existing concepts and previous research. Follow-up research should expand the scope of study to include other possible uses of interior space such as performing simultaneous activities. Additionally, in subsequent studies, it is possible to present the dimensions and mechanisms of space by experimenting with a wider range of subjects through mock-up and actual vehicle that reflects design elements that consider the problems and phenomena that occur when using the flexible spatial components.

6. Conclusions

This study aimed to analyze the relationships among various elements related to the use of space in a face-to-face seating arrangement. We used mock-up, observational surveys, questionnaires, and the think-aloud research method within an ethnographic observation framework. Most of the previous studies did not consider the confined space of an autonomous vehicle. In our study, the experimental setting was created using the dimensions of an SUV interior so that the participants would experience the actual space that autonomous vehicles are initially likely to have. We found that various activities and actions can occur in a face-to-face seating arrangement. It is important to recognize that face-to-face seating arrangements are not just to facilitate conversation but can be seen as an environment in which each passenger can conduct other in-vehicle activities individually. In conclusion, our findings suggest that needs for activities be considered when designing spatial components in a face-to-face seating arrangement. This study has certain limitations as the experiment was conducted using a mock-up, not an actual vehicle interior space.

In subsequent studies, it will be important to create an experimental environment that is quite similar to an actual vehicle.

Author Contributions: Conceptualization, J.K., D.J.; methodology, J.K.; investigation, J.K.; formal analysis, J.K.; resources, J.K.; data curation, J.K.; visualization, J.K.; writing—original draft preparation, J.K.; validation, D.J.; writing—review and editing, D.J.; supervision, D.J.; project administration, D.J.; funding acquisition, D.J. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Technology Innovation Program (10079996, Development of HVI technology for autonomous vehicle driver status monitoring and situation detection) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from every subject involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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