COGNITIVE AND PHYSICAL FACTORS IN CHANGES TO THE AUTOMOBILE DRIVING ABILITY OF ELDERLY PEOPLE AND THEIR MOBILITY LIFE

– Questionnaire Survey in Various Regions of Japan –

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We analyzed cognitive and physical changes in driving by aging drivers based on responses to a questionnaire delivered to elderly and non-elderly drivers in various regions of Japan. Factor analysis of the 27-item questionnaire indicated that four factors related to cognitive change while three factors related to driver physical change and task-oriented change. We adopted the situation awareness cognitive-behavioral model to examine relationships among derived factors. The four cognitive factors corresponded to the elements in the cognitive-behavioral process for automobile driving. The other three factors impact the cognitive-behavioral process. Investigation of the effects of demographic (age and area of residence) and automobile usage characteristics (driving frequency and annual mileage) on the factor scores revealed that cognitive and physical changes depended not only upon age but also on area of residence and automobile usage. From this results, daily driving experience was considered to influence cognitive and physical function. We analyzed the effect of cognitive and physical change on the level of satisfaction in using other modes of transportation from the perspective of elderly mobility. We found that drivers who scored higher for change in automobile driving skills remained satisfied with automobile use but not the use of public buses.

Key Words: Factor analysis, Elderly drivers, Cognitive-behavioral model, Demographic characteristics, Automobile use

1. INTRODUCTION

As the elderly population has grown so has the number of elderly automobile users, but the use of automobiles by the elderly has both a positive side and a negative side. On the positive side, automobiles enable the elderly to expand the scope of their lives and lead richer lives. On the negative side, the elderly are involved in accidents whose cause is believed to lie in some functional change of the elderly. Finding a balance – achieving safe mobility – is an important issue for transportation policy and automotive technology. For this, we must gain a better understanding of elderly mobility and, by clarifying the driving capabilities of the elderly, consider what kind of support is required to secure their mobility.

Surveys of automobile use by the elderly, such as driving frequency and driving objective, have been conducted in various countries. They reveal that aging leads to reduced driving frequency and distance traveled, more trips to established destinations near the home and less driving at night and in poor weather. Accidents involving the elderly have also been studied[1]. Analysis based on accidents in Japan shows that many accidents occur at intersections and involve a failure to stop, running a red traffic light or interfering with traffic that has the right of way. Accidents are an end result of driving behavior and governed by a variety of factors, so it can be difficult to determine when fault lies with the driver. Therefore, to investigate the relationship between accidents and the mistakes that elderly drivers are aware they make in ordinary driving, Parker, et al. used the Driving Behavior Questionnaire (DBQ) developed by Reason, et al. to survey 2,000 people concerning mistakes they made during everyday driving (errors that could lead to an accident and lapses without such a direct link) and their accident experience[2]. They found that the number of accidents experienced for which the elderly driver was at fault could be explained by annual mileage and the likelihood of errors and lapses. To reduce mistakes by the elderly in everyday driving there is a need to clarify the relationship between mistakes and functional changes in the elderly. Factor analysis of the results of a survey conducted by Aberg, et al. that supplemented the DBQ with original questions and targeted 2,000 people aged 18 to 70 indicated that aging brings higher scores for inattention errors[3]. Nevertheless, inattention errors address only the failure to see signs and signals and the vagueness of memory during driving – merely a subset of cognitive function. A number of studies have evaluated functionality related to cognitive-behavior in a laboratory setting and investigated its relationship to driving behavior. McKnight, et al. analyzed the relationship between unsafe behavior like incidents while driving and the results of various tests of sensory, cognitive and motor function. They found that the results of functional tests and the frequency of unsafe behavior were positively correlated. However, because test results for the various functions were themselves highly correlated, they were unable to uncover the inner structure and identify which functional changes were most problematic[4]. In the same way, Schlag found that aging has a pronounced effect on the results of functional tests but found little difference in actual driving behavior[5]. These studies have used laboratory testing to investigate cognitive-behavioral function but their functional tests have been abstract ones like visual acuity test and reaction time testing. It is unclear how these correspond to the cognitive-behavior required in an actual driving situation.

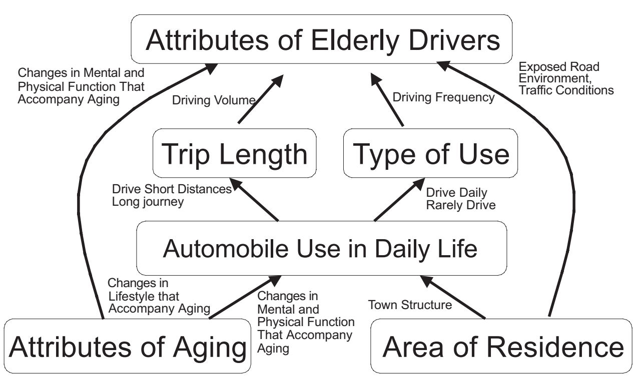

Fig. 1 Factors related to the attributes of elderly drivers

Therefore, we have conducted a survey using a questionnaire concerning aging-related changes in respondent self-awareness of cognitive capabilities for driving skill in everyday driving. We have used factor analysis to try to clarify the inner structure of changes in driving skills. Here, questions were chosen to relate to changes in cognitive-behavioral capabilities and physical capabilities as the human capabilities required for driving.

Also, because the cognitive-behavior capabilities required for driving may vary by driving environment, and changes in capability may differ depending upon whether one drives daily or only infrequently (Figure 1), we surveyed elderly drivers over a broad area in Japan in order to analyze the relationships between changes in driving capability and both region and automobile usage. In addition, because there is a need to consider alternative modes of transportation for securing mobility for elderly persons whose driving skills have declined[6], we also analyzed the impact of a change in driving skill on the level of satisfaction in using other modes of transportation.

2. SURVEY METHODOLOGY

2.1 Survey subjects

We conducted a questionnaire survey of male and female drivers aged 60 and over from around Japan who drive on a regular basis and a control group of drivers in their 50s[7]. In order to enable detection of regional differences, subjects were selected from a dispersed geographical area.

Valid responses were received from a total of 202 people: 86 aged in their 50s (60 men and 26 women), 68 in their 60s (42 men and 26 women) and 48 in their 70s (28 men and 20 women). Respondents came from 83 municipalities in 19 prefectures. These municipalities were classified into three categories based on their rates of automobile ownership: areas with fewer then 0.6 automobiles per household, areas with more than 0.6 but fewer than 1.0 automobiles per household, and areas with 1.0 or more automobiles per household. Because automobiles per household is an index of the degree to which automobiles are a necessity in everyday life, the three categories are called, respectively, low automobile reliance areas, moderate automobile reliance areas, and high automobile reliance areas. Low automobile reliance areas are metropolitan areas such as Tokyo's 23 wards and Yokohama

City where the road transportation environment is characterized by heavy traffic volume, a complicated road network and development of public transportation. Moderate automobile reliance areas are regional cities or suburban areas such as Nagoya City and Chiba City. High automobile reliance areas are regional cities like Niigata City and Gifu City (Table 1).

2.2 Automobile usage

Annual mileage and driving frequency were used as indices of automobile use. For annual mileage, respondents could choose from seven categories: less than 1,000km, less than 3,000km, less than 5,000km, less than 7,000km, less than 10,000km, less than 15,000km, and 15,000km or more. For driving frequency, respondents could choose from five categories: no more than 1 or 2 days a month, 3 or 4 days a month, 1 or 2 days a week, 3 or 4 days a week, and 5 or more days a week. In addition, in order to survey respondents' attitudes toward automobiles and other modes of transportation, they were asked to respond concerning the importance of, and their level of satisfaction with, buses, trains, automobiles, taxis and bicycles. For "importance," respondents chose from four categories: would have great difficulty without it, would have some difficulty without it, would have little difficulty without it, and would have no difficulty without it. For "level of satisfaction," respondents chose from five categories: very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied.

2.3 Items concerning change to cognitive and physical driving capabilities

In developing the questionnaire, we selected items related to situations in which elderly drivers consciously felt themselves to be cognitively weak in assessing traffic conditions while driving, situations in which they felt their vehicle control skills had declined, and situations in which they felt their sensory or motor functions had declined. Initially, we selected 19 items concerning traffic situation assessment, 16 concerning vehicle control skills, and 27 concerning physical function. A preliminary study led to the elimination of items that were largely duplicative or difficult to answer, resulting in a final survey of 11 items concerning situation assessment, 11 concerning vehicle control skills, and 14 concerning changes to physical function (Table 2).

Respondents were asked to think of each item in terms of whether they had experienced change relative to the past, and then select from four categories: extremely applicable, very applicable, somewhat applicable, and not applicable. To further clarify the meaning of "relative to the past," respondents were also asked when they first noticed the change and to choose from four responses: recently, beginning 3 to 5 years ago, beginning 5 to 10 years ago, and beginning no less than 10 years ago. The addition of this question made it easier for subjects to respond from the standpoint of the changes accompanying aging.

Table 1 Area categories

Category	Examples of Major Cities
Low Automobile Reliance Areas (Fewer than 0.6 automobiles per household)	Tokyo's 23 Wards Yokohama City
Moderate Automobile Reliance Areas (Fewer than 1.0 automobiles per household)	Nagoya City Chiba City
High Automobile Reliance Areas (At least 1.0 automobiles per household)	Niigata City Gifu City

3. FACTOR ANALYSIS

3.1 Determining the number of factors

Using as variables each of the 36 items on the questionnaire of 202 elderly drivers and the control group that concerned change in cognitive and physical function while driving, we conducted a factor analysis of all respondent data and attempted to group the variables. Factor analysis, excluding nine variables that had low correlation to any other variables, found that the cumulative contribution ratio through seven factors was roughly 50% and beginning to approach the saturation point on the cumulative contribution ratio curve so seven factors were adopted. Varimax rotation was employed to make it easier to interpret the meaning of the factors.

3.2 Interpreting factor axes

For this study, factor axes were interpreted as follows based on the factor loadings and the content of the items that were most highly weighted. Table 3 summarizes the items included in each factor and the factor loading for each question.

(1) Factor 1: Change in Visual Function

Highly weighted items in Factor 1 indicate that signals and road signs have become difficult to see. Therefore, Factor 1 was interpreted as change in visual function.

Table 2 Items in questionnaire

Change in Assessment of Traffic Situation (11 Questions)	Timing right turns at intersections has become more difficult. Cars parked on the street have begun to concern me. I have begun to worry about children jumping out in residential areas. I now have difficulty deciding quickly what to do when emergency vehicles approach. I no longer want to drive on narrow streets. Entering tunnels now makes me feel a sense of pressure. While driving, the movements of motorcycles, bicycles and pedestrians now annoying. Overtaking forward vehicles now makes me feel nervous. While driving, the movements of surrounding vehicles now concern me. I now take time to select route to my destination when I watch for road signs. I feel difficult to decide which lane to travel in on multi-lane roads.
Change in Vehicle Control Skills (11 Questions)	Parallel parking has become difficult. Backing into parking spaces has become difficult. Turning the steering wheel to turn at intersections has become reluctant. I can no longer stop exactly where I want to at stop lines. I often find the distance between my car and the one in front has widened. I now have more difficulty driving with the flow of traffic. I think my driving skills have dropped with age. Passing other cars on narrow roads has become more difficult. I sometimes find myself traveling at unexpected speed. I am no longer able to immediately step on the brake when the light turns red. I now find that I more frequently step on the brake for every little thing while driving.
Change in Physical Function (14 Questions)	Signage is more difficult to see at night. I now get tired even when driving for only a short time. I can no longer maintain my concentration while driving. I now have difficulty recognizing the color of traffic signals. I now have difficulty seeing the arrows on traffic signals. My hands now tire quickly when gripping the steering wheel. Getting in and out of the automobile now takes some effort. It now takes some effort to turn around and look back when backing up. The door now feels heavier. I now have difficulty seeing the speedometer and other instruments. I now get tired if the ride is not a smooth one. Keeping the brake down while stopped at a traffic light has become a chore. It now takes time for my eyes to adapt darkness after entering a tunnel. I now have difficulty reading signs even during the day.

(2) Factor 2: Change in Precision Driving Operations

Highly weighted items in Factor 2 are related to parking situations and running on narrow streets, and include "backing into parking spaces has become difficult," "parallel parking has become difficult" and "I no longer want to drive on narrow streets." These driving situations concern little space in the driving environment relative to vehicle size and require an accurate sense of vehicle location, precise operation of the steering wheel, and a division of attention both front and back and left and right. Therefore, Factor 2 was interpreted as change in precision driving operations.

(3) Factor 3: Change in Ability to Execute Driving Operations

Highly weighted items in Factor 3 indicate an inability to execute the necessary operations that accompany decisions to turn or stop while driving and include "turning the steering wheel to turn at intersections has become reluctant," "I can no longer stop exactly where I want to at stop lines," and "I can no longer maintain my concentration while driving." Therefore, Factor 3 was interpreted as change in ability to execute driving operations.

Table 3 Factor loading

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
I now have difficulty seeing the arrows on traffic signals.	0.807	0.033	0.155	0.101	0.071	0.165	0.056
I now have difficulty recognizing the color of traffic signals.	0.741	0.021	0.095	-0.018	0.017	0.068	0.100
I now have difficulty reading signs even during the day.	0.715	0.107	0.087	0.104	0.125	0.179	0.073
Signage is now more difficult to see at night.	0.615	0.323	0.056	0.114	0.258	0.146	0.053
Backing into parking spaces has become difficult.	0.139	0.774	0.221	0.215	0.148	0.107	0.144
Parallel parking has become difficult.	0.110	0.685	0.296	0.219	0.247	0.068	0.020
Turning the steering wheel to turn at intersections has become reluctant.	0.082	0.240	0.757	0.126	0.069	0.198	0.204
I can no longer stop exactly where I want to at stop lines.	0.116	0.094	0.672	0.130	0.110	-0.041	0.065
I can no longer maintain my concentration while driving.	0.189	0.202	0.507	0.156	0.241	0.452	0.062
While driving, the movements of surrounding vehicles now concern me.	0.071	0.113	0.112	0.796	0.134	0.093	0.089
While driving, the movements of motorcycles, bicycles and pedestrians now annoying.	0.118	0.097	0.061	0.743	0.097	0.220	0.011
Overtaking forward vehicles now makes me nervous.	0.008	0.242	0.122	0.693	0.223	-0.016	0.042
I often find the distance between my car and the one in front has widened.	0.130	0.089	0.244	0.212	0.673	0.062	0.105
I now find that I more frequently step on the brake for every little thing while driving.	0.201	0.279	0.160	0.272	0.597	0.158	0.094
I now have more difficulty driving with the flow of traffic.	0.022	0.253	0.437	0.059	0.590	0.204	-0.011
I now get tired even when driving for only a short time.	0.257	0.186	0.158	0.086	0.190	0.725	-0.004
I now get tired if the ride is not a smooth one.	0.280	0.074	0.116	0.241	0.094	0.561	0.078
Getting in and out of the automobile now takes some effort.	0.387	0.151	0.302	0.147	0.151	0.078	0.730
It now takes some effort to turn around and look back when backing up.	0.356	0.396	0.246	-0.018	0.136	0.198	0.352
It now takes time for my eyes to adapt darkness after entering a tunnel.	0.417	0.264	0.110	0.138	0.325	0.356	0.257
I now feel difficult to decide which lane to travel in on multi-lane roads.	0.107	0.396	0.239	0.203	0.416	0.334	0.189
I now have difficulty deciding quickly what to do when emergency vehicles approach.	0.137	0.417	0.087	0.097	0.320	0.308	0.135
I am no longer able to immediately step on the brake when the light turns red.	0.095	0.123	0.491	-0.009	0.230	0.139	0.075
I now take time to select route to my destination when I watch for road signs.	0.227	0.297	0.095	0.325	0.472	0.217	0.006
I no longer want to drive on narrow streets.	0.075	0.485	0.221	0.407	0.169	0.190	-0.005
I think my driving skills have dropped with age.	0.223	0.229	0.395	0.226	0.290	0.122	-0.008
Passing other cars on narrow roads has become more difficult.	0.148	0.403	0.414	0.327	0.331	0.142	-0.173

(4) Factor 4: Change in Ability to Assess Traffic Conditions

Highly weighted items in Factor 4 include "while driving, the movements of surrounding vehicles now concern me," "while driving, the movements of motorcycles, bicycles and pedestrians now annoying," and "overtaking forward vehicles now makes me nervous." These all indicate a sense that, on roads with other traffic, assessing the actions of surrounding vehicles has become more difficult. Therefore, Factor 4 was interpreted as change in ability to assess traffic conditions.

(5) Factor 5: Change in Ability to Keep Up With Traffic Flow

Highly weighted items in Factor 5 include "I often find the distance between my car and the one in front has widened," "I now find that I more frequently step on the brake for every little thing while driving," and "I now have more difficulty driving with the flow of traffic." These all suggest a difficulty in keeping up with the overall flow of traffic. Therefore, Factor 5 was interpreted as change in ability to keep up with traffic flow.

(6) Factor 6: Change in Workload Sensitivity While Driving

Highly weighted items in Factor 6 are related to a sense of fatigue while driving. Therefore, Factor 6 was interpreted as change in workload sensitivity while driving.

(7) Factor 7: Change in Motion Control Function

Highly weighted item in Factor 7 is related to bodily motion while getting in and out of the vehicle. Therefore, Factor 7 was interpreted as change in motion control function.

4. CORRESPONDENCE BETWEEN FACTORS OF CHANGE IN DRIVING FUNCTION AND THE DRIVER COGNITIVE-BEHAVIOR MODEL

4.1 Cognitive-behavior model

There were seven factors of cognitive and physical change accompanying aging of which respondents were self-aware: “change in visual function” (F1) relating to the visibility of traffic signals, “change in precision operations” (F2) relating to driving operations while parking or on narrow streets, “change in ability to execute driving operations” (F3) relating to steering and stopping, “change in ability to assess traffic conditions” (F4) related to surrounding vehicles and pedestrians, “change in ability to keep up with traffic flow” (F5) related to driving with the flow and following distance, “change in workload sensitivity” (F6), and “change in motion control function” (F7) related to driver physical function such as strain associated with getting in and out of a vehicle. If we could gain an understanding for the structure that joins these factors, it would be easier to interpret their relationship to differences in region and automobile usage. Because the questionnaire items adopt the perspectives of situation awareness and sensory-motor physical function, we attempted to interpret the factors based on the human cognitive-behavior model.

The cognitive-behavior (or information processing) model generally used for automobile driving is the three-step process model of cognition, decision and operation. Panek, et al. proposed a four-step model (perception, cognitive process, decision-making/choice of action, and execution) for information processing while driving, suggesting that aging had an effect on each step[8]. In addition, Mica R. Endsley has proposed a five-step situation awareness (SA) model[9,10] of information processing: perception, comprehension of situation, projection of future status, decision, and performance of action. This information processing process is also affected by task/system factors that vary with the task being performed and individual factors that vary with the individual conducting the task.

4.2 The cognitive-behavior process and factors of change in cognitive and physical function

Among the factors derived through factor analysis, Factors 6 and 7 concern changes in workload sensitivity and motion control function; they represent characteristics of the driver rather than of the cognitive-behavioral process during driving. Factor 2 concerns change perceived only during specific driving tasks pertaining to parking and driving on narrow streets, and relates to all stages of the cognitive-behavior process. These three factors are seen as having an effect on the cognitive-behavior process overall while the remaining four factors corresponded to elements in the cognitive-behavior process.

“Change in visual function” (F1) relating to the visibility of traffic signals indicates a change in how objects outside the vehicle are perceived while driving, and can be regarded as a change in the “perception” process. “Change in ability to assess traffic conditions” (F4) related to surrounding vehicles and pedestrians includes prediction of the behavior of other traffic participants, and can be regarded as a change in the “comprehension of situation” or “projection of future status” process. “Change in ability to keep up with traffic flow” (F5) related to driving with the flow and following distance includes selecting from actions such as deciding to accelerate based on perceptual input like following distance information, can be interpreted as a change in the ability to make decisions about whether to narrow the following distance, and can be regarded as a change in the “decision making” process. “Change in ability to execute driving operations” (F3) relating to steering and stopping can be regarded as a change in the “execution” process. In this way, four of the factors derived through factor analysis can be interpreted as roughly corresponding to the sub-processes in the cognitive-behavior process.

Figure 2 summarizes our model including the four-step cognitive-behavior process (perception, comprehension of situation, decision-making, and execution) described above, as well as the task/system factors and individual factors (driver attributes) that have an effect on the process overall based on the Endsley model. The

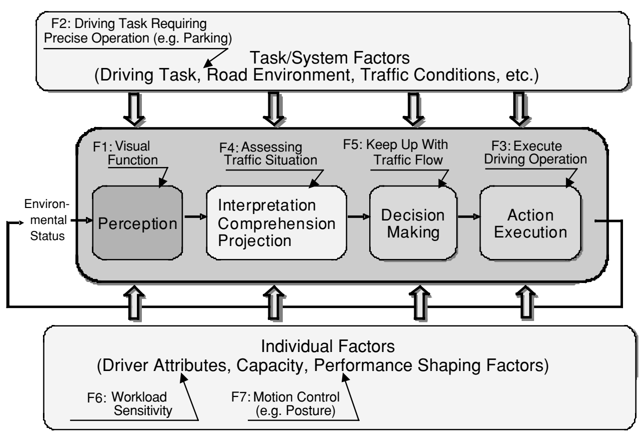

Fig. 2 The driver cognitive-behavior model and factors corresponding to its elements

four sub-processes of the cognitive-behavior process correspond, in order, to Factor 1, Factor 4, Factor 5 and Factor 3. Task/system factors correspond to “change in precision operations” (F2) relating to driving operations that require special driving skills while parking or on narrow streets. Individual factors correspond to “change in workload sensitivity” (F6) and “change in motion control function” (F7).

5. CHANGE IN DRIVING COGNITIVE-BEHAVIOR FUNCTIONS WITH AGING

Using the factor scores obtained through factor analysis, we analyzed respondent trends by factor. The factor analysis here was based on the responses of 202 subjects, included the control group in their 50s as well as subjects in their 60s and 70s, and we cannot know whether the factors were derived based solely on changes due to aging. Therefore, we divided respondents into three age groups (50s, 60s and 70s) and looked for age-based changes in the scores for each factor.

(1) Aging Trends for “Change in Perceptual Ability”

Although not a significant difference, “change in visual function” was highest for those in their 50s and lower for those in their 60s and 70s (Figure 3a).

Visual performance, particularly that of dynamic visual acuity, is a physical function that begins to decline with aging in one’s 50s[11]. Because visual performance is one of the earliest changes to come with aging, it may be a factor of particular concern to drivers in their 50s who are becoming senior citizens.

(2) Aging Trends for “Change in Ability to Comprehend Situations”

The score for “change in ability to assess traffic conditions” (that is, change in ability to comprehend situations) increases with age, with a significant difference between respondents in their 50s and respondents in their 70s (Figure 3b). In order to assess road traffic conditions such as other automobiles, motorcycles and pedestrians, one must distribute one’s attention appropriately among the required objects; our results suggest the elderly have a reduced ability to divide their attention broadly.

(3) Aging Trends for “Change in Decision-Making Ability”

The average score for “change in ability to keep up with traffic flow” (that is, change in decision-making ability) increases with age. However, the difference is slight and not significant (Figure 3c).

(4) Aging Trends for “Change in Ability to Execute”

“Change in ability to execute driving operations” (that is, change in ability to execute) increases with age, with a significant difference between respondents in their 50s and 70s and between respondents in their 60s and 70s, and a conspicuous change in function among those in their 70s (Figure 3d). Ability to execute means the ability to actually carry through with the required actions. Aging may bring difficulty in investing the information processing resources needed to continue executing.

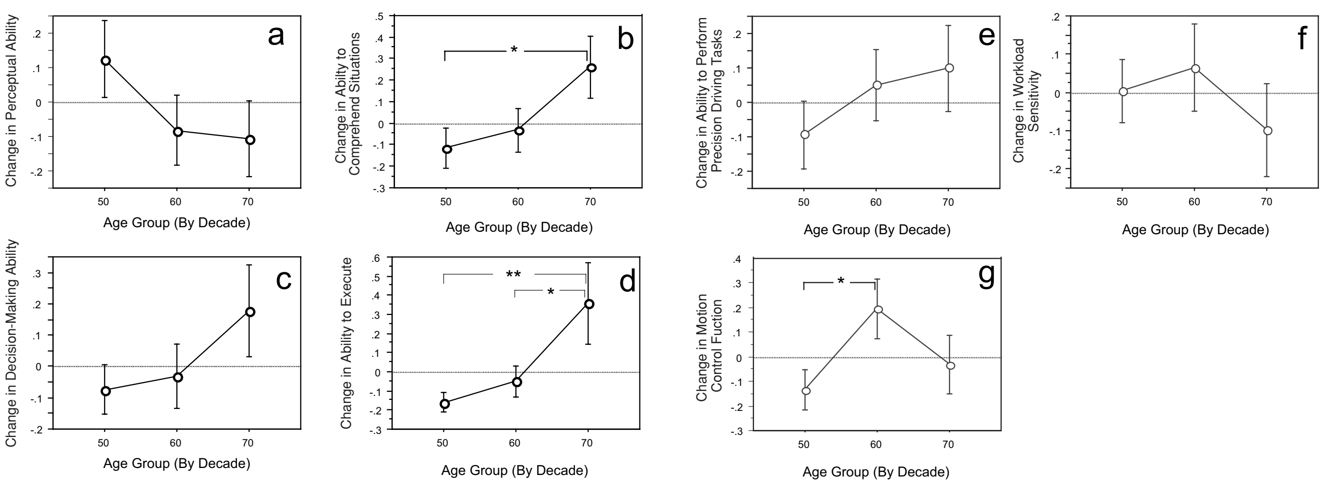

Fig. 3 Aging-related changes to factor scores corresponding to cognitive and physical function elements of the driver cognitive-behavior process

(5) Aging Trends for "Change in Ability to Perform Tasks Requiring Precision Operation"

Scores for change in ability to perform tasks requiring precision operation (that is, change in ability to perform tasks such as parking) were higher for respondents in their 60s and 70s than for respondents in their 50s, although the difference was not significant (Figure 3e). This supports the well-known tendency for the elderly to have difficulty with parking.

(6) Aging Trends for "Change in Workload Sensitivity"

Scores for change in workload sensitivity while driving were nearly the same for respondents in their 50s and 60s but declined for respondents in their 70s (Figure 3f). Workload sensitivity (that is, fatigue while driving) appears to be felt most strongly during early aging but the differences are small and it is unclear whether change is associated with aging.

(7) Aging Trends for "Motion Control Function"

Change in motion control function such as getting in and out of vehicles is a factor felt strongly and significantly by respondents in their 60s relative to respondents in their 50s. Because for Japanese the range of motion for joints such as the shoulder and hip begins to decline in one's 60s[12], one expects to see great change in motor control function related to the bending of the body required to get in and out of automobiles.

We investigated change due to aging for the factors corresponding to the elements of the cognitive-behavior model. The ability to comprehend situations and the ability to execute were found to change with aging. The score for visual function was highest among respondents in their 50s, while respondents in their 60s were most strongly conscious of change in the motor control function needed to get in and out of automobiles. Consciousness of change in driving-related functions does not simply increase uniformly with aging but in some cases reaches its highest point during early or middle aging.

6. THE RELATIONSHIP BETWEEN AUTOMOBILE USAGE AND CHANGE IN DRIVING COGNITIVE-BEHAVIOR FUNCTIONS WITH AGING

6.1 Driving tasks and automobile usage

Driving an automobile requires paying attention simultaneously to a number of locations and making quick decisions and actions. The tasks of everyday life performed in the home might be considerably different cognitive-behavior than driving tasks. Therefore, one can imagine that the information processing required for driving may vary depending upon whether one is accustomed to driving or not. One's driving experience could serve as an index of familiarity with driving but most elderly drivers have long driving experience, making it a poor index. We therefore decided to use driving frequency and annual mileage as our index. Driving frequency and annual mileage are correlated variables but drivers who drive frequently and have low annual mileage are taking short trips while drivers who drive infrequently and have high annual mileage are taking long trips. The former are the sort of people who use their automobiles for daily shopping trips in the neighborhood while the latter are the sort of people who use their automobiles for long journeys.

Driving tasks vary depending upon the road traffic environment in which they are conducted. For example, urban areas with many motorcycles, bicycles and pedestrians require divided attention to comprehend and predict their various actions but on a major suburban road with few traffic, the primary task is following the road geometry (e.g. curvature). We address this difference in ordinary road traffic environments by looking at differences in area of residence.

6.2 The relationship between automobile usage and change in driving cognitive-behavior functions with aging

6.2.1 Method of analysis

We analyzed change in driving cognitive-behavior functions with aging by looking at differences in driving frequency, annual mileage and area of residence. Data for driving frequency and annual mileage were collected using, respectively, five and seven categories. Nevertheless, for the sake of simplicity, we have divided both driving frequency and annual mileage into two groups (high and low) for comparative purposes. Driving frequency was divided into "no more than one or two times a week" (55 respondents) and "at least three or four times a week" (147 respondents), while annual mileage was divided into "less than 5,000km a year" (104 respondents) and "at least 5,000km a year" (92 respondents). Areas of residence were categorized as "low automobile reliance areas," "moderate automobile reliance areas" and "high automobile reliance areas."

6.2.2 Results of analysis

(1) Aging Trends for "Change in Perceptual Ability"

Looked at by age alone, respondents in their 50s tended to show the highest awareness of change but this tendency is not seen in drivers who drive at least 5,000km a year. There is a significant difference between drivers in their 50s who drive at least 5,000km a year and those in their 50s who drive less than 5,000km a year. In other words, one can say that even among drivers in their 50s, those who drive a lot are unaware of a change in their visual function. Comparing high and low driving frequency, there are significant differences within age groups, with the low frequency driving group strongly aware of a change in visual function. Comparing different areas, there is no clear tendency (Figure 4). Seen in terms of driving frequency and annual mileage, change in visual function is something most noticed by drivers in their 50s who drive infrequently and not for long distances.

(2) Aging Trends for "Change in Ability to Comprehend Situations"

This was a function that exhibited a clear change with aging, but a comparison of differences in driving frequency indicates that drivers in all age groups who drive more frequently are more aware of the change. Seen in terms of regional difference, there is a significant difference between age groups in high reliance areas (rural areas). At the same time, seen in terms of the difference in annual mileage, low-mileage drivers show a strong increase in awareness of functional change in their 70s (Figure 5). High reliance areas may be characterized by a greater awareness of functional change because many drivers in high reliance areas drive frequently. In other words, drivers in rural areas with generally less need to perform the task of assessing the activity of surrounding traffic may undergo a change with aging in their ability to pay attention to other vehicles. Furthermore, low-mileage drivers may become strongly aware of functional change when they reach their 70s.

(3) **Aging Trends for "Change in Decision-Making Ability"**

We were unable to identify any significant differences when looking at driving frequency, annual mileage and region with respect to change in the ability to make decisions such as driving with the flow of traffic and adjusting driving behaviors in accord with surrounding vehicles (Figure 6). With respect to annual mileage, those in the low-mileage group in all age groups were more strongly aware of change. In other words, drivers who take long trips for travel are less aware of this functional change; experience of the constant decision-making of long-distance driving probably makes one less aware of functional change.

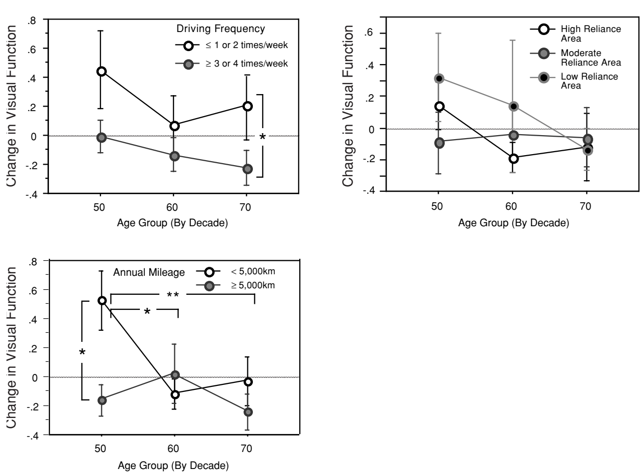

Fig. 4 Differences in change in perceptual ability with age by automobile usage and area

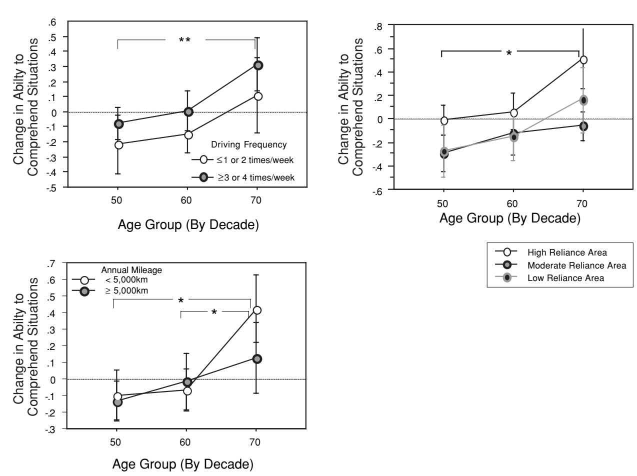

Fig. 5 Differences in change in ability to comprehend situations with age by automobile usage and area

(4) Aging Trends for "Change in Ability to Execute"

Looking at differences in driving frequency and annual mileage with respect to change in the ability to execute driving operations like braking, we found that drivers in their 70s who drive infrequently and have low annual mileage are strongly aware of such change (Figure 7). Looking at regional differences, there is little difference by age group in low reliance areas (urban areas) but in moderate and high reliance areas the scores significantly increase with aging. For high reliance areas, in particular, the score for those in their 70s is significantly higher than that for both those in their 50s and those in their 60s. The observed change with aging in moderate and high reliance areas suggests that driving in a road traffic environment with fewer traffic signals and intersections increases one's awareness of change in ability to execute.

(5) Aging Trends for "Change in Ability to Perform Tasks Requiring Precision Operation"

Awareness of change in the ability to perform tasks such as parking that require precision operation increases strongly with aging. However, analyzed in terms of differences in driving frequency and annual mileage, we can see that drivers in their 50s who drive frequently and have high annual mileage are unaware of such change (Figure 8). Among drivers who drive frequently, those in their 60s show an abrupt increase in awareness, suggesting a change brought about by early aging. Comparing regions, there is an increase with age in high reliance areas but not in moderate and low reliance areas. This suggests a relationship to the many narrow parking spaces and narrow streets in urban areas. Coping with tasks like parking is not difficult for drivers accustomed to such tasks.

(6) Aging Trends for "Change in Workload Sensitivity"

When looked at by age alone, workload sensitivity, which corresponds to the tendency to become fatigued while driving, exhibited no clear trend with aging. Looking at differences in driving frequency, however, revealed a significant difference between the low-fre-

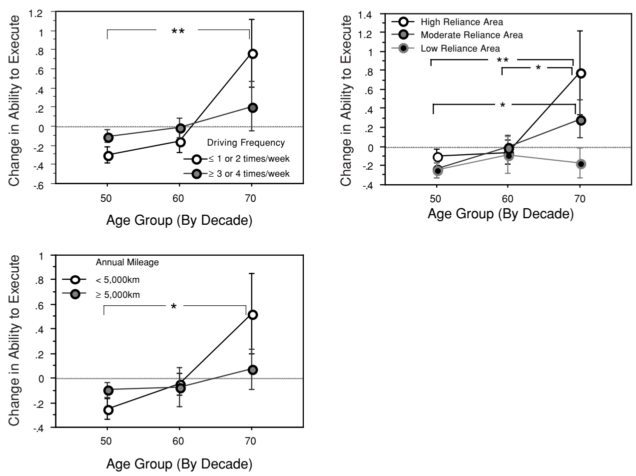

Fig. 7 Differences in change in ability to execute with age by automobile usage and area

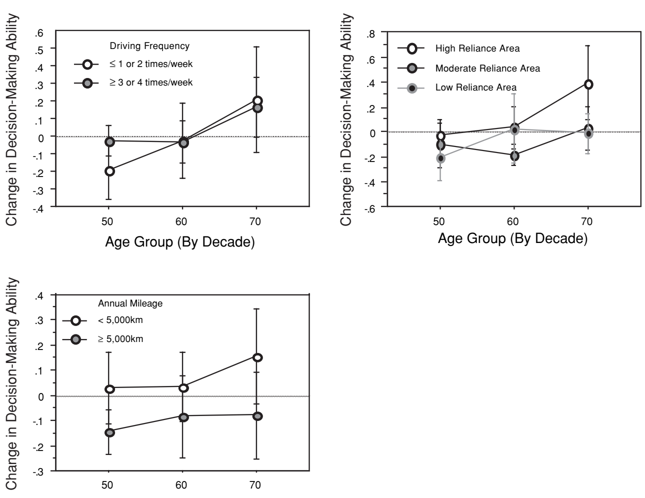

Fig. 6 Differences in change in decision-making ability with age by automobile usage and area

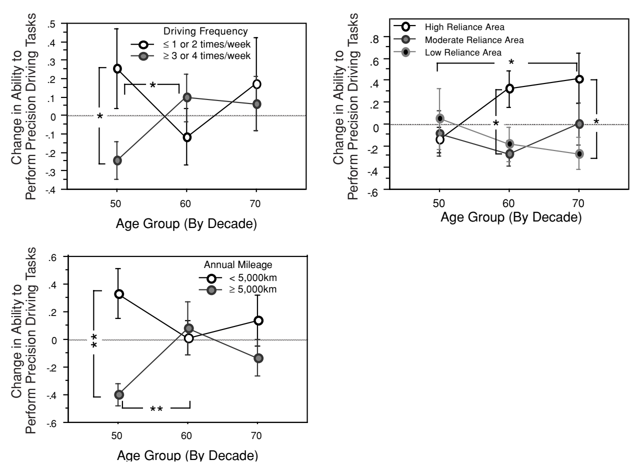

Fig. 8 Differences in change in ability to perform precision driving tasks with age by automobile usage and area

quency group and the high-frequency group among those in their 70s. This suggests that workload sensitivity is higher among those in their 70s who drive infrequently (Figure 9). That this trend is not exhibited for annual mileage suggests that it is not a matter of the distance driven but of increased awareness of change due to infrequent opportunities to drive. There was nothing distinctive about regional differences.

(7) Aging Trends for "Motion Control Function"

Those in their 60s who drive frequently and have high annual mileage are most strongly aware of change in motion control function in getting in and out of vehicles (Figure 10). In other words, drivers who use their automobiles the most become aware of changes to motion control function in their 60s.

7. CHANGE IN COGNITIVE-BEHAVIOR IN DRIVING TASKS AND USE OF TRANSPORTATION MODES

We analyzed the relationship between the degree of driving-related cognitive and physical change and the level of satisfaction with and importance of automobiles and other modes of transportation. We divided the factor scores for change in cognitive and physical function that were derived through factor analysis into high and low groups and compared these high and low groups for level of satisfaction with and importance of each transportation mode to clarify whether a change in driving functions has an effect on the usability of other transportation modes. For each transportation mode, our analysis excluded respondents who said they almost never used it.

There was little difference in importance by functional change but there were differences in the level of satisfaction in using various transportation modes by degree of functional change. Those cognitive and physical functional changes among the seven functions for which there was a difference are listed below:

- Visual: The high change group was less satisfied with buses, trains, automobiles and bicycles.
- Comprehension: The high change group was less satisfied with bicycles.
- Decision-Making: The high change group was less satisfied with buses.
- Execution: The high change group was less satisfied with buses.
- Workload: The high change group was less satisfied with buses, trains and automobiles.
- Motion Control: The high change group was more satisfied with trains.

Respondents with a change in the cognitive and physical abilities of visual function, decision-making ability, execution and workload sensitivity were less satisfied to use buses, suggesting that change in such functions has an effect on bus use (Figure 11). Using the bus requires various cognitive-behavioral functions as users look at destination routes and fare tables, select routes, decide which bus to board, decide which stop to get off, and execute the disembarkation. In addition, the vibration of the bus appears to lead to the same workload as an automobile. Meanwhile, the high change group for abil-

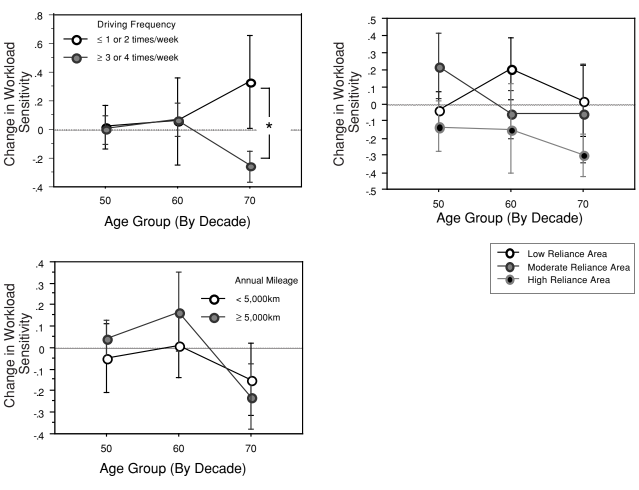

Fig. 9 Differences in change in workload sensitivity with age by automobile usage and area

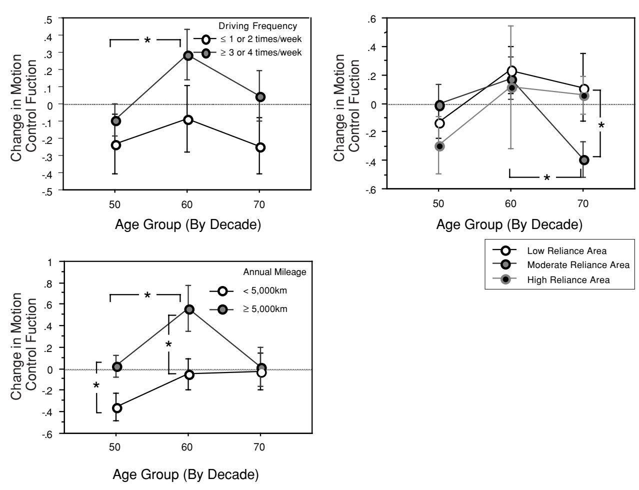

Fig.10 Differences in change in motion control function with age by automobile usage and area

ity to comprehend situations was slightly more satisfied with the bus. When riding the bus, unlike when driving an automobile, there is no need to assess traffic conditions; the slightly higher satisfaction level seems to reflect the fact that this ability is not required for bus ride. The same was true for the motion control function, probably because it is easier to get on and off a bus.

Respondents with a change in the visual function and workload sensitivity were less satisfied with using trains. This seems to reflect the fact that using the train requires one to read route maps and station signage, and causes fatigue due to the vibration of the carriage. Unlike buses, there was no apparent relationship with functional change in decision-making ability and execution, which suggests that determining which train to ride and which station to get off is not difficult, and that getting on and off a train requires little physical burden. Respondents reporting a large degree of change in motion control function for automobile driving were more highly satisfied with trains; for those who have difficulty getting in and out of automobiles, trains are an attractive alternative mode of transportation.

Respondents with a change in visual function and ability to comprehend situations were less satisfied with bicycles. Riding a bicycle requires taking in visual information and assessing the behavior of surrounding automobiles and pedestrians, making it less satisfying for those who have experienced a change in these abilities.

Respondents with a change in the visual function and workload sensitivity were less satisfied with using automobiles. Even a change in higher-order cognitive functions like assessing conditions and decision-making did not lead to lower satisfaction with using automobiles, suggesting that people will continue to use automobiles even if they are aware of a change in their driving skills.

8. DISCUSSION

8.1 Changes in driving skills and the cognitive-behavior process

Focusing on cognitive and physical abilities, we conducted a questionnaire survey concerning self-awareness of change in driving skills in various driving situations and used factor analysis to derive seven factors of change in driving skills. An attempt was made to interpret the derived factors as corresponding to the information processing elements in the cognitive-behavior model. As a result, we interpreted four of the seven factors as corresponding to four of the elements in the cognitive-behavior process. That the derived factors correspond to elements of the cognitive-behavior process means that change due to aging occurs for each of the process elements and that the changed elements vary by driver.

8.2 Changes in cognitive and physical function due to automobile usage

Using factor scores to analyze differences not only by age but also by aspects of automobile usage such as driving frequency, annual mileage and driving area, we found that there were differences in the functional change by automobile usage for each element in the cognitive-be-

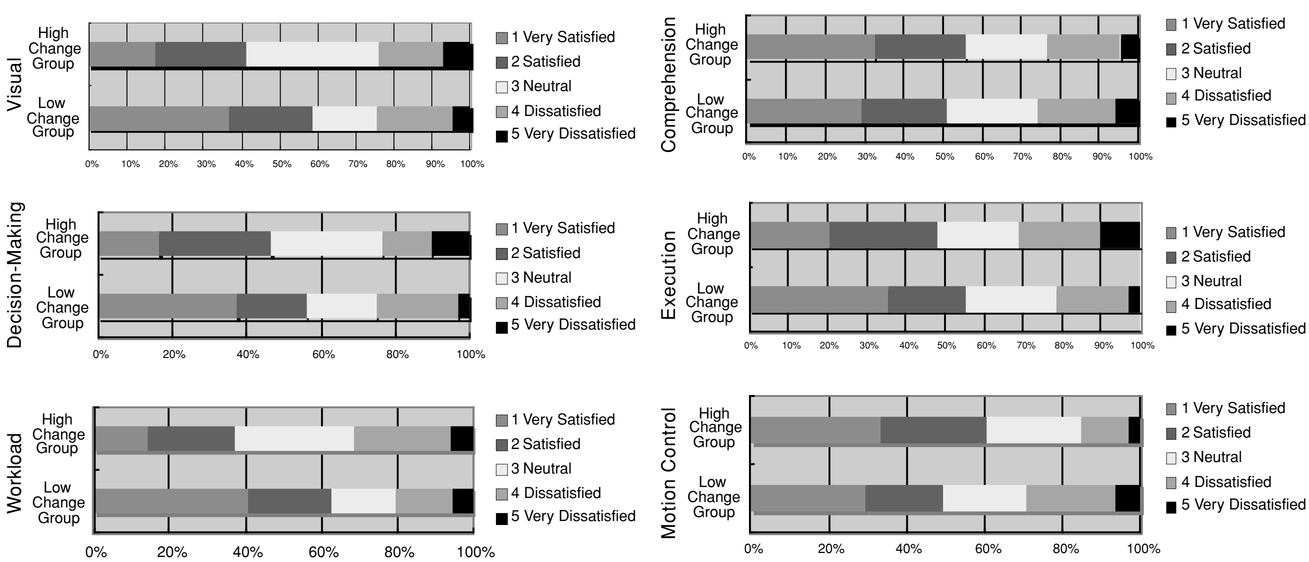

Fig. 11 Differences in level of satisfaction with bus use by degree of change in driving skill

havior process. Among drivers in their 50s, not yet senior citizens, those who drive infrequently were most aware of a change in the visual function needed to see traffic signals and road signs. Awareness of a change in the ability to comprehend situations and assess the behavior of other road traffic grew stronger with aging among respondents in their 60s and 70s, a trend that was most pronounced in rural areas. Drivers who rarely have to assess traffic conditions are aware of a change in their ability to do so. Awareness of a change in decision-making ability such as selecting driving actions grows stronger with aging and particularly among drivers who rarely drive long distances. This suggests that greater opportunities to engage in continuous driving reduce awareness of change in decision-making ability. Awareness of a change in the ability to execute actions (such as braking or turning) grows with aging, a trend that tended to be seen among rural drivers and was especially pronounced for infrequent drivers in their 70s.

Our investigation has shown that aging-related changes in cognitive and physical function involved in driving an automobile are not determined simply by age but are also affected by driving frequency and location. Regional differences were found for the ability to comprehend situations, the ability to execute and the ability to perform precision tasks. For each of these, awareness of functional change tended to be low in low reliance areas and higher in high reliance areas. It may be that there is a lower awareness of change when situations requiring a given ability are frequently encountered. Whether this is because functional decline is prevented when the ability is frequently required or because some compensating mechanism has developed in frequent driving situations that prevents the decline, though either may be possible.

Differences in functional change by type of automobile usage were observed for all functions. Functional change was most pronounced with infrequent driving and low annual mileage for all four of the functions in the cognitive-behavior process as well as tasks requiring precision operation and workload sensitivity. This suggests that driving regularly can prevent functional change. On the other hand, frequent drivers with high annual mileage were most aware of change in the motion control function. Frequent drivers are probably most strongly aware of a change in motion control because it is a physical function not reinforced by driving.

As discussed above, frequent drivers who live in low reliance areas with complicated road traffic environments have lower awareness of change in their driving skills, suggesting that the experience of everyday driving has the effect of maintaining driving skills. However, the possibility that this is due either to the fact that drivers who are least aware of a change in their driving skills keep using automobiles, or to the fact that drivers in rural areas continue to drive even though they are aware of a change in their driving ability, cannot be discounted in this study.

8.3 Changes in driving skills and the importance of modes of transportation

When we compared levels of satisfaction with the use of various other modes of transportation, we found that drivers who were aware of a decline in their driving skills were also less satisfied with buses. Under the existing transportation system, buses are often regarded as an alternative to private automobiles but there are a number of issues that must be solved to make buses an attractive alternative mode of transportation for those whose driving skills have declined. With respect to satisfaction with automobiles, drivers who are aware of a decline in vision and sense a high workload are less satisfied, but changes in other functions were found to have no effect. The limited effect on levels of satisfaction suggests that the benefit of automobile use are great.

9. CONCLUSIONS

We used a questionnaire survey to derive factors of change in cognitive and physical functions related to driving by elderly drivers. We compared our factor analysis results and the cognitive-behavior model and interpreted the four factors correspond to cognitive processes (perception process, situation awareness process, decision-making process, and execution process) in the cognitive-behavior model. The remaining three factors corresponded to task/system factors and individual factors of change in the ability to perform tasks such as parking that require precision operation, tendency to fatigue, and change in motion control function related to getting in and out. Because the factors obtained through factor analysis correspond to the cognitive-behavior processes for automobile driving, aging-based changes are different among aged drivers.

To see if aging-based changes in the cognitive-behavior process vary by automobile driving habits or location, we analyzed the relationship between factor scores and driver area of residence, driving frequency and annual mileage. We found the ability to comprehend situations, the ability to execute and the ability to perform precision tasks were influenced by region, with drivers in low automobile reliance areas less aware of functional change. This suggests that encountering driving environments in which such abilities are required on a daily basis reduces functional change. Both driving frequency and annual mileage had an effect on all factors, suggesting that driving habits do influence change in driving skills.

We analyzed the relationship between functional change in automobile driving skills and the level of satisfaction with other modes of transportation. We found that change in driving skills does affect the level of satisfaction with other modes of transportation. A decline in driving skills brings a decline also in the level of satisfaction with buses and other forms of public transportation, suggesting that even if a change in driving skills leads to the use of public transportation, there is a possibility that this will not bring satisfactory mobility.

There is, therefore, a need to consider the benefit of using automobiles, the characteristics of other modes of transportation and the changes in cognitive and physical function that differ by individual and region when thinking about automobile technology and transportation systems for securing mobility for the elderly.

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