

THE IMPACT ON DRIVING PERFORMANCE FROM GRADED COGNITIVE LOAD WITH VISUO-SPATIAL AND PHONOLOGICAL PROCESSING OF VISUAL AND AUDITORY INPUT.

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ABSTRACT

The majority of human factors in traffic accidents are the result of cognitive error. Errors of cognition are produced by the relationship of the cognitive load of the traffic environment and vehicle interior environment with the driver's information processing. The cognitive load while driving is made up of the loads from the sense organs of sight and of hearing. The resources used for processing of visuo-spatial information and phonological information are independent, and it has been proposed that each processing resource has its capacity. It has been reported in previous research that when the cognitive load increases, driving becomes unstable. On the other hand, it has been reported in other research that when the cognitive load becomes high, driving becomes stable. Considering that cognitive load has been reported as an influence that both increases and decreases performance, it is conceivable that performance varies with the type and magnitude of the cognitive load from each category of information, and that a moderate degree of load exists under which performance reaches its highest level. For this paper, a driving simulator was used to study the influence on driving performance caused by graded cognitive load from the visuo-spatial process and phonological process of input from the sense of sight and sense of hearing. In testing, drivers drove on a course with a series of gentle curves while responding to n-back tasks that use visual/visuo-spatial process and auditory/phonological process. The result was that in the case of n-back tasks using visual/visuo-spatial processing, driving performance was diminished as the difficulty of the n-back task increased. However, in the case of n-back tasks using auditory/phonological processing, driving performance did not change when the difficulty of the n-back task increased. Also, although the load under which performance reaches its highest level was not determined, it was confirmed that auditory n-back tasks do have loads under which performance tends not to change. This is thought to be because the visual/visuo-spatial process used in driving and other information processes tend not to influence each other, while the same information processes did interfere with each other. The conclusion is that, in order to maintain stable driving performance, it can be considered important that the cognitive load on the driver does not interfere with the processing of visual/visuo-spatial information while driving.

INTRODUCTION

Honda aims for zero fatalities in traffic accidents involving Honda motorcycles or automobiles worldwide by 2050. Of human factors resulting in fatal accident cases in Japan, 68.8% are due to cognitive error such as not confirming safety, intrinsic absence of attention ahead, extrinsic absence of attention ahead, and so on [1]. Driving scenes have various different items of information that drivers should perceive. Drivers perceive not only the lane they are driving in, but also traffic signs, traffic participants, the vehicle interior environment, and so on. The traffic environment information that is being perceived is constantly changing as driving proceeds. On country roads, there is less traffic environment information, and distracted driving and other such errors cause pedestrians to be overlooked. On the other hand, there is more traffic environment information in urban areas, and information overload can result in delay in noticing pedestrians. These kinds of errors of cognition occur through the relationship between the cognitive load from the traffic environment and vehicle interior environment and the driver's information processing [2]. Information processing of the cognitive load takes place by means of the working memory. Alan Baddeley and Graham Hitch have proposed a working memory that is considered to be made up of a visuo-spatial sketch pad and phonological loops [3]. According to the multiple resource model proposed by Christopher D. Wickens, the resources for processing visuo-spatial information and those for phonological information are independent, and each processing resource is proposed to have its capacity [4]. These suggest that different information processing domains tend not to influence each other while information processing domains that are the same interfere with each other. During driving, visual/visuo-spatial processing is considered to make up most of the processing. For that reason, the input of visuo-spatial process information during driving can be considered likely to influence driving.

There have also been a number of research reports that cognitive load has an influence on driving performance. According to Uno, et al., when cognitive load rises to a high level, variation in lateral movement of the vehicle becomes larger when following a vehicle ahead and driving is said to become unstable [5]. On the other hand, according to Johan Engstrom, et al., when cognitive load rises to a high level, there are fewer standard deviations of lateral position during lane keeping tasks, and driving is reported to be stable [6]. In other words, cognitive load can be considered to have an influence that both increases and decreases performance. In addition, the Yerkes–Dodson law hypothesized that when arousal and load increase, performance increase, but when arousal and load increase too much, then performance decreases instead [7]. Based on this hypothesis, it can be considered possible that there is a degree of load under which performance reaches its highest level.

From these proposals and hypotheses, it can be considered that cognitive load has an influence on driving performance, and further that it is possible that the way performance is influenced when the load is in a separate domain that does not overlap with processing for driving differs from when it is in the same domain that does overlap with that processing. It can also be considered that there is a moderate degree of load under which performance reaches its highest level. For this paper, a driving simulator (DS) was used to study the influence on driving performance from the graded cognitive load of visuo-spatial processing and phonological processing of input from the sense of sight and sense of hearing. This testing was reviewed and passed by Bioethics Committee Meetings for Hondas R&D activities. (Bioethics Committee No. 99HM-020H)

METHOD

System

Driving task (lane center tracing task) Driving performance was evaluated by use of the DS. The test participants drove in the middle of the roadway on a winding course made up of a series of curves. In order to continuously place a cognitive load on them and also to continuously measure their driving performance, the curvature of the winding course curves was gradually changed in a design intended to require drivers to be constantly steering.

Cognitive tasks (n-back tasks) In order to control the cognitive load, n-back tasks were used as the cognitive tasks. N-back tasks are typical tasks used to impose a cognitive load, and there are many cases of their use in other research as well [8]. In the n-back task, the subject is given numbers or letters at regular intervals, and if the number or letter is the same as the one n times before, the subject is to respond with a positive sign (○) and if it is different, then the subject is to respond with a negative sign (×) (Fig. 1). In n-back tasks, using a higher number n makes the load larger, and so it is possible to control the load. For the present research, a preliminary experiment was conducted with reference to previous research and a number or letter was presented at 4-second intervals [9]. A single n-back trial consists of a total of 37 issues with seven right answers. What was presented in the n-back tasks was a graphic that uses the visual sense to employ visual/visuo-spatial processing that overlaps with the information processing during driving, and a voice that uses the sense of hearing to employ auditory/phonological processing that does not overlap with driving (Fig. 2). The graphic, taking previous research as a reference [10], was a figure with a 4×4 grid, as shown in Fig. 3, containing red circles at two locations. Nine types of these figures were prepared and displayed randomly. Figure 4 shows where the figure was displayed. It was confirmed through advance testing that this display location does not overlap with the location of the line of sight during driving and the location is also easy to check when driving through left and right curves, and this configuration was determined. For the voice, nine integers from one to nine were played back randomly. In order to control the conditions, headphones were worn in the same way during the graphic n-back tasks. During the graphic n-back tasks, however, no voice sound was played, and the headphones were muted.

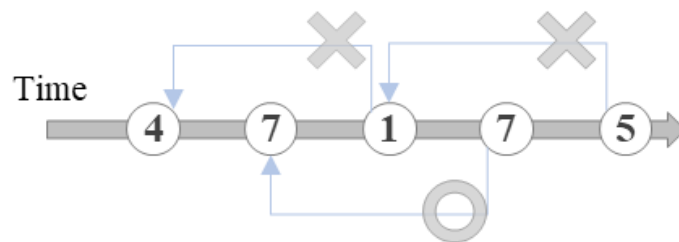


Figure 1. Example of 2-back task.



Figure 2. Content presented in n-back tasks.

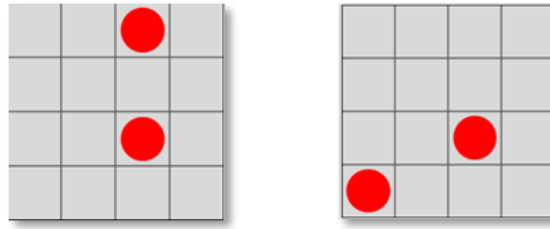


Figure 3. Example of graphic in graphic n-back task.

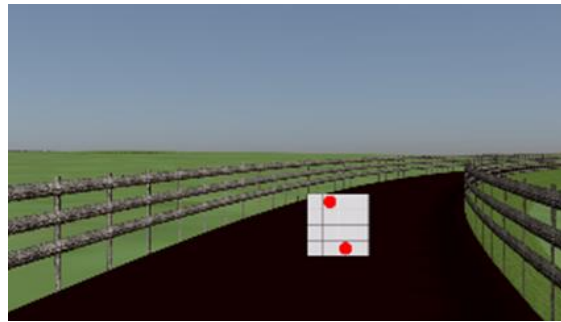


Figure 4. Graphic n-back task display location.

Subjective evaluation In order to confirm the extent to which test participants engaged in the tasks, the test participants subjectively evaluated the degree of task achievement and the degree of effort. For the degree of achievement, evaluations were made of the n-back tasks and driving tasks severally. The evaluations used the visual analogue scale (VAS), where a score of zero indicates a task was extremely unachieved and a score of 100 indicates it was extremely achieved. For the degree of effort, a score of zero indicates extremely little effort was made and a score of 100 indicates extreme effort was made. These two subjective evaluation indices were evaluated on a range from zero to 100.

Test Procedure

A total of 18 men and women (average age 37.6 years) whose consent for testing was obtained participated in the tests. This research was conducted with review and approval by Bioethics Committee Meetings for Hondas R&D activities (Bioethics Committee No. 99HM-020H). Test participants were also given an explanation of the purpose of the research using the consent forms and their cooperation was requested. Test participants whose consent was obtained also signed the consent forms.

Figure 5 shows the flow of the test as a whole. To accustom the test participants to the n-back tasks, familiarization with n-back tasks was conducted in advance using 3-back tasks. The test participants drove a winding course in the DS environment. They were instructed to keep their position in the middle of the course roadway as much as possible. The driving speed was set at a fixed 50 km/h, and test participants only operated the steering. To accustom the test participants to driving in the middle of the roadway, they were fully familiarized with the DS steering operation and the appearance of the field of vision. For this familiarization, both the driver view (Fig. 6) and the overhead view (Fig. 7) were displayed together, and the test participants were made able to drive in the middle of the course roadway while checking the view of the subject vehicle’s position and the field of vision in

the driver view. After the test participants' driving familiarization, the driving for the test itself was done. The test itself was conducted in 10 trials in order to have a mixture of each type of n-back task. The graphic and sound n-back tasks were both conducted under the five conditions of no n-back, 1-back, 2-back, 3-back, and 4-back. However, the order of the n-back tasks was made random in order to do away with order effects. The test of n-back tasks under five conditions was taken as one set, and two sets were conducted. The driving for a single trial consisted of a reference interval in which only driving is done and an evaluation interval in which n-back tasks and driving are done simultaneously. In order to keep responses to n-back tasks in the evaluation interval from interfering with driving, test participants responded using the paddle shift button on the steering wheel instead. After the driving ended, test subjects made subjective evaluations of their own driving and the n-back tasks, which completed one trial.

Graphic n-back tasks and sound n-back tasks were conducted on separate days.

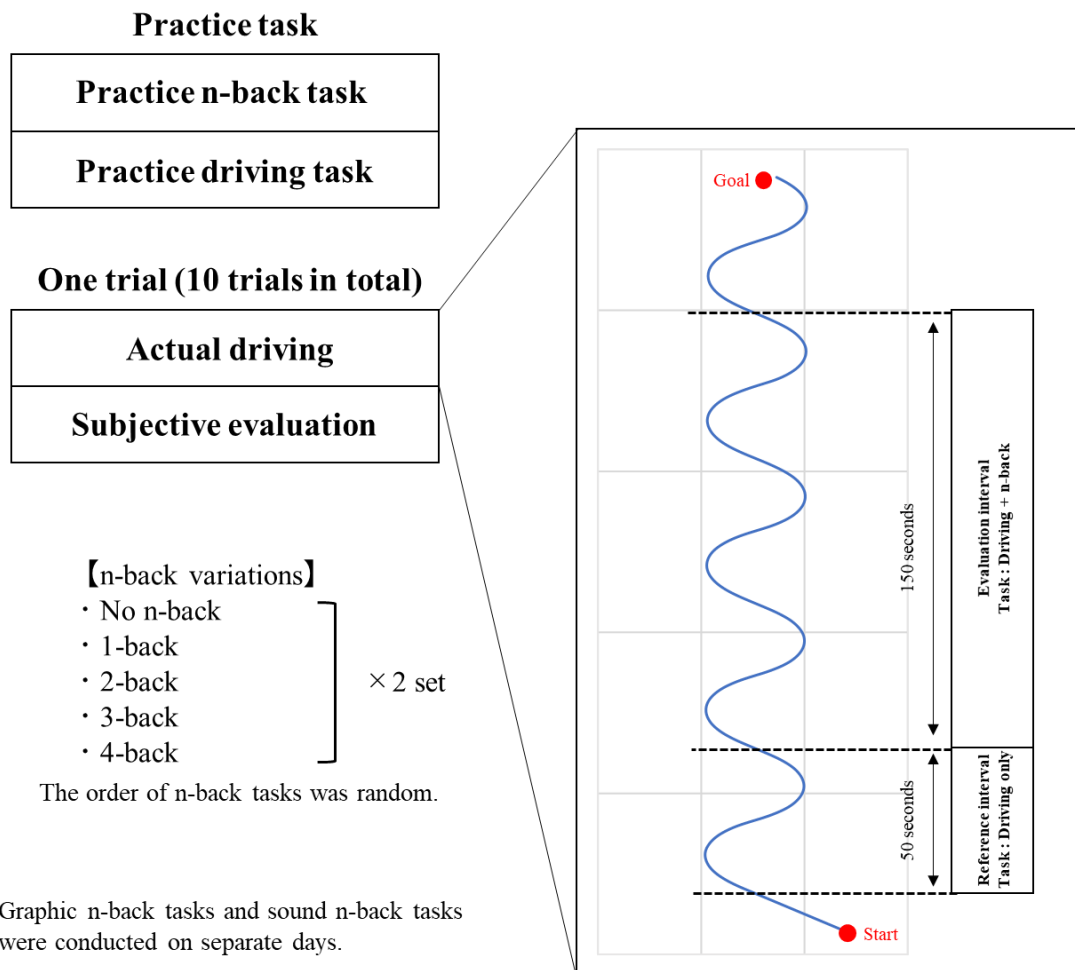


Figure 5. Test flow.

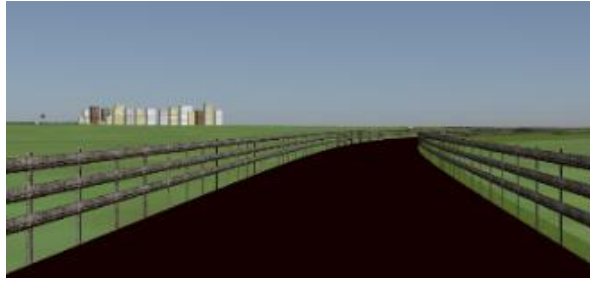


Figure 6. Display when driving in the middle of the course roadway (driver view).

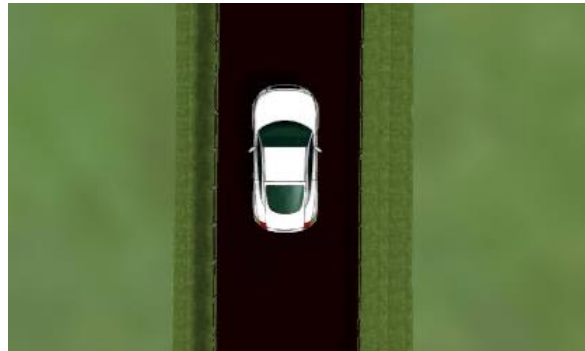


Figure 7. Overhead view during familiarization drive.

ANALYSIS METHOD

Evaluation of Cognitive Tasks (n-back Task Response Reaction Time/Number of Right Answers)

In order to check whether the cognitive load on test participants was successfully being imposed gradually, the performance of the n-back tasks was evaluated. For performance, the n-back task response reaction time and the number of right answers were calculated. The response reaction time was taken to be the time from when the n-back task was presented until the response was made by the paddle shifter. The number of right answers was taken as the number of responses for which the response given was that the number or the graphic presented was the same as that n times before. The number of right answers can be for a maximum of seven tasks.

Driving Performance Evaluation (Lateral Offset from Course)

In order to confirm the influence of n-back tasks on driving, the reference interval of each trial was used as a standard in evaluating the driving performance in the evaluation interval. It was reported from previous research that, compared to when no cognitive load is imposed, variation in lateral movement of the vehicle becomes larger when following a vehicle ahead when a cognitive load is imposed. This can be considered to be because the number of times of significant deviation from the course increases due to drivers' inability, as a result of the cognitive load, to notice the lateral offset until it has grown large. In order to evaluate the degree of which the task of driving in the middle of the course is achieved, the position of lateral offset from the middle of the course roadway was calculated (Fig. 8). Fig.9 shows the calculation method of the amount of lateral offset for one trial. The average lateral offset position of the reference interval in the data for all trials by that individual was reduced from the lateral offset position data of the evaluation interval of one trial. The absolute value of this subtracted

lateral offset position data of the evaluation intervals was averaged, and the amount of lateral offset was calculated for one trial. As there are two trials for each n-back task, the first and second trials are averaged and these amount of lateral offsets were taken as the driving performance evaluation values for each n-back task.

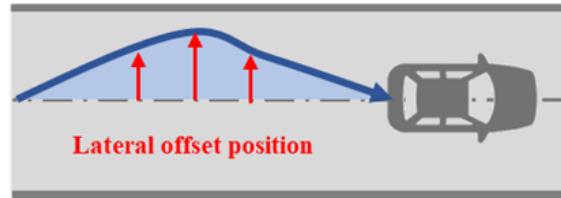


Figure 8. Lateral offset position from the middle of the course roadway.

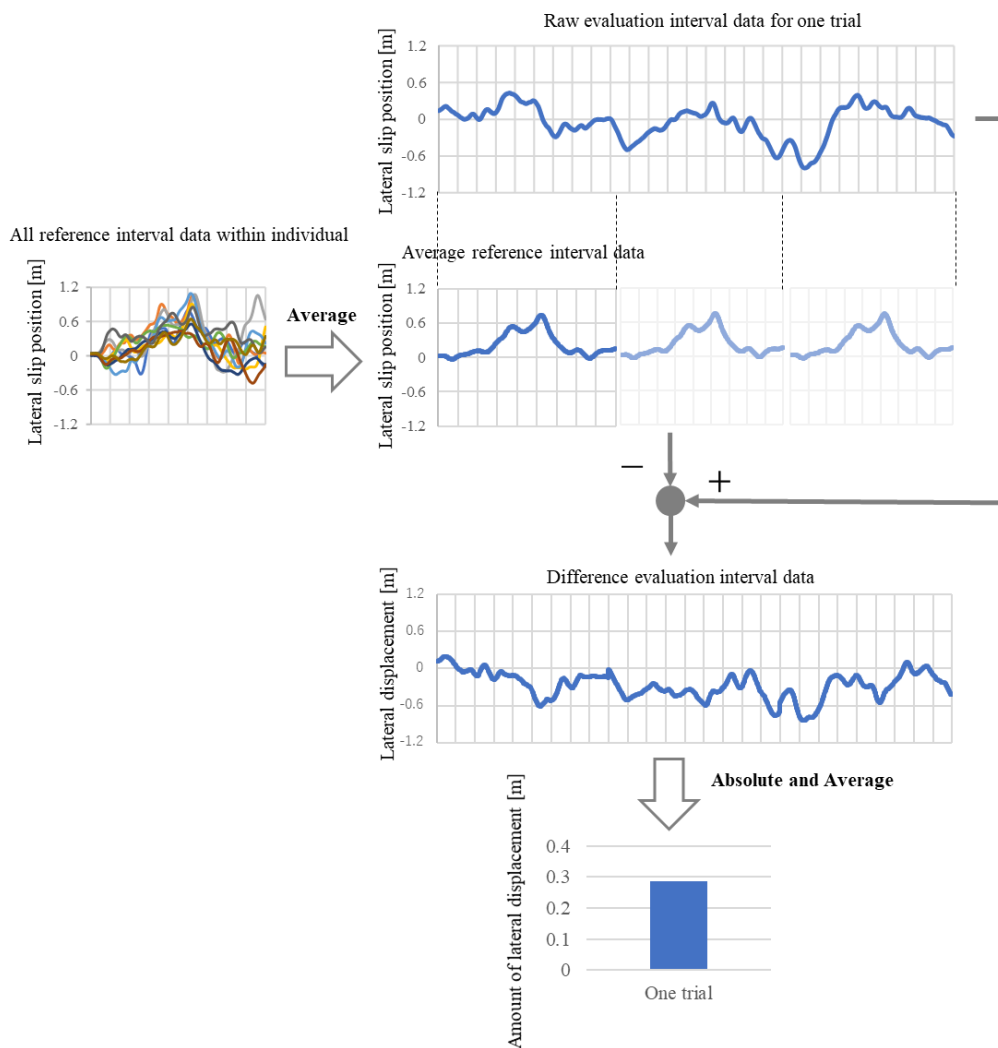


Figure 9. Amount of lateral offset calculation method for one trial.

RESULTS

Cognitive Task Evaluation (n-back Response Reaction Time/Number of Right Answers and Subjective Evaluation)

Figures 10 and 11 show the response reaction times and the number of right answers to the visual and auditory n-back tasks that were the cognitive tasks. For both the visual and auditory n-back tasks alike, increasing the size of the number n resulted in slower reaction times and the number of right answers decreased. Differences were apparent in the visual and auditory n-back task scores.

In addition, Fig. 12 and Fig. 13 show the average subjective achievement and subjective effort for all test participants in each n-back task. The subjective achievement results show that as the n numbers grew higher, the tasks were not achieved for both visual and auditory n-back tasks. The n-back task scores and subjective achievement evaluation suggest that the n-back tasks were successful in gradually changing the test participants' cognitive load. In both the visual and auditory n-back tasks, the subjective effort indicated that the greatest effort was achieved with the 2-back tasks.

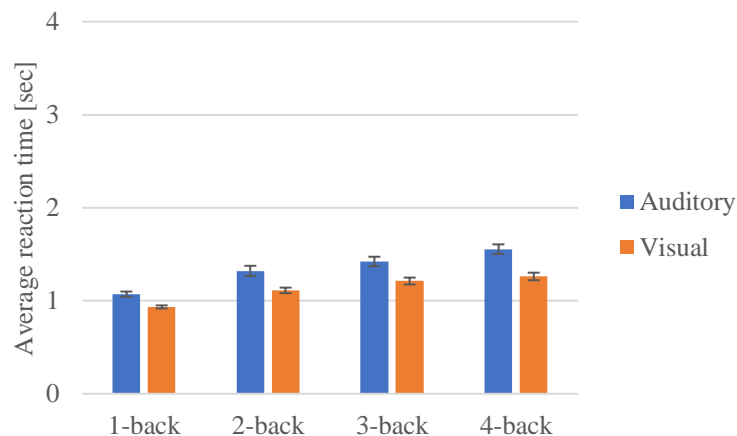


Figure 10. Average reaction times in visual and auditory n-back tasks.

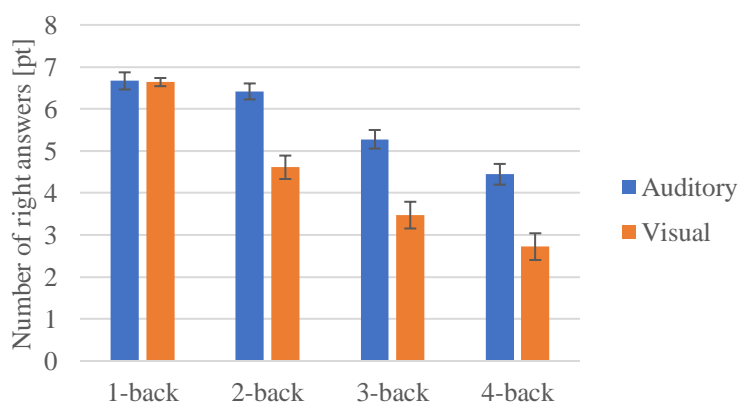


Figure 11. Average number of right answers in visual and auditory n-back tasks.

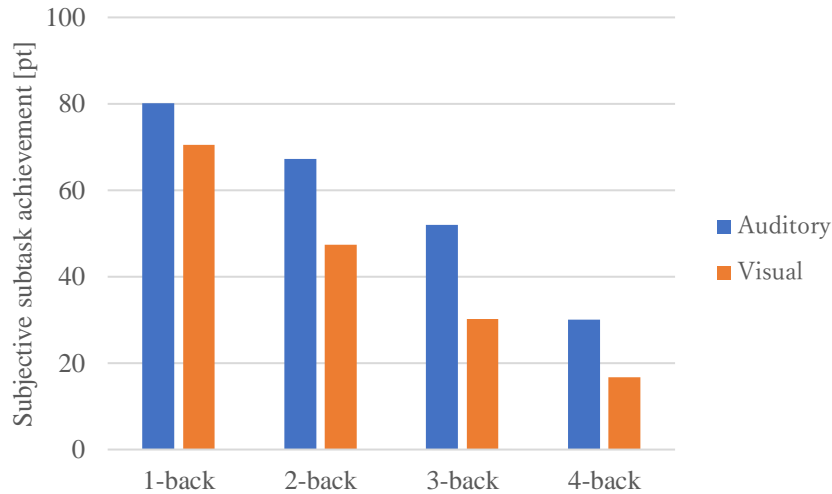


Figure 12. Subjective achievement in visual and auditory n-back tasks.

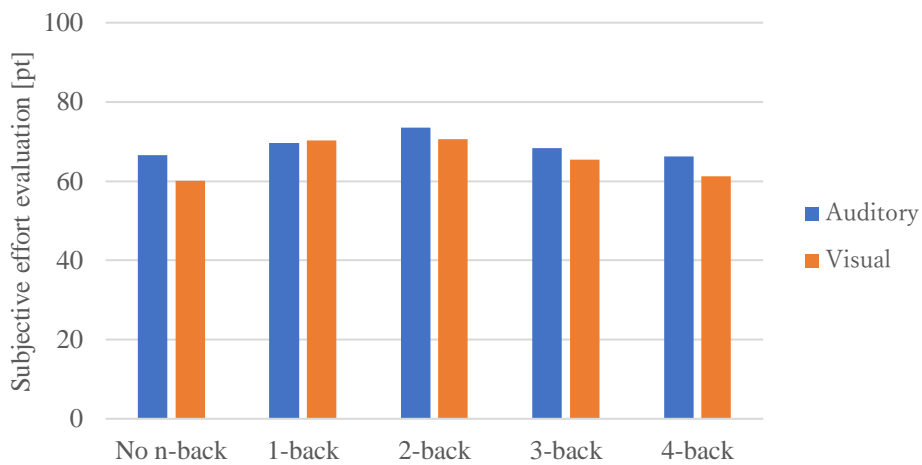


Figure 13. Subjective effort of driving and n-back tasks combined.

Relationship of Degree of Cognitive Load (n-back Tasks) and Driving Performance

Figures 14 and 15 show the amount of lateral offset in the course roadway during the evaluation interval for the visual and auditory n-back tasks, respectively. In the visual n-back tasks, when t-tests were conducted from 1-back to 4-back tasks with respect to the no n-back tasks, there was a significant difference between the no n-back tasks and all of the n-back tasks. As the cognitive load increased, the amount of lateral offset increased. In the auditory n-back tasks, when t-tests were conducted from 1-back to 4-back tasks with respect to the no n-back tasks, the amount of lateral offset did not show a large, significant difference between the no n-back tasks and 1-back to 4-back tasks.

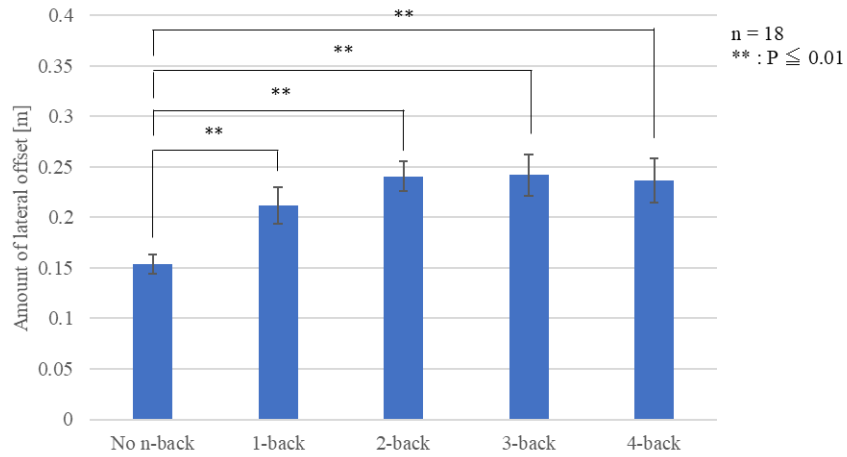


Figure 14. Amount of lateral offset in the visual n-back tasks.

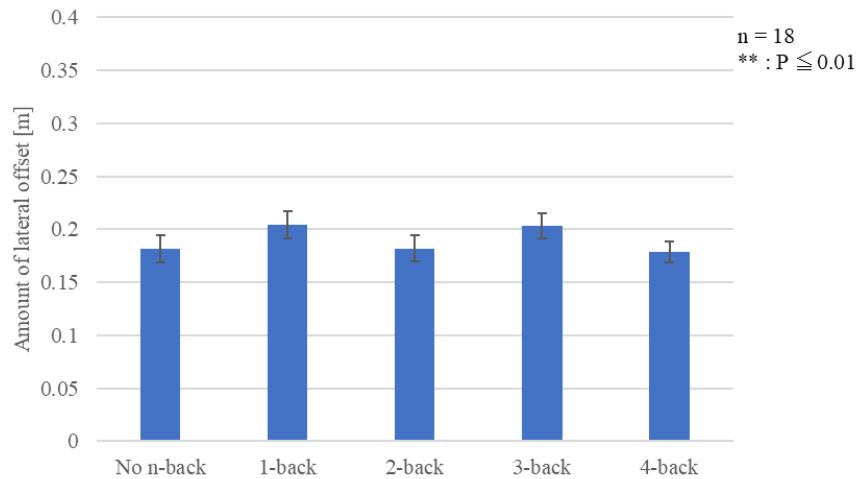


Figure 15. Amount of lateral offset in the auditory n-back tasks.

Differences in Cognitive Processing Domains and the Relationship with Driving Performance

In order to compare the driving performance when visual and auditory n-back tasks were performed, the 1-back tasks, that the difference in the amount of lateral offset between the visual and auditory tasks was slight, were taken as a reference and the change in the amount of lateral offset with the n-back tasks was confirmed. Figure 16 shows the lateral offset relative ratio of each n-back task with the 1-back task as the reference. When t-tests were performed on visual n-back tasks and auditory n-back tasks, a significant difference in the amount of lateral offset between them was observed in the 2-back and 4-back tasks. In the visual and auditory tasks, there was a tendency for the amount of lateral offset that was observed to be larger in the visual tasks.

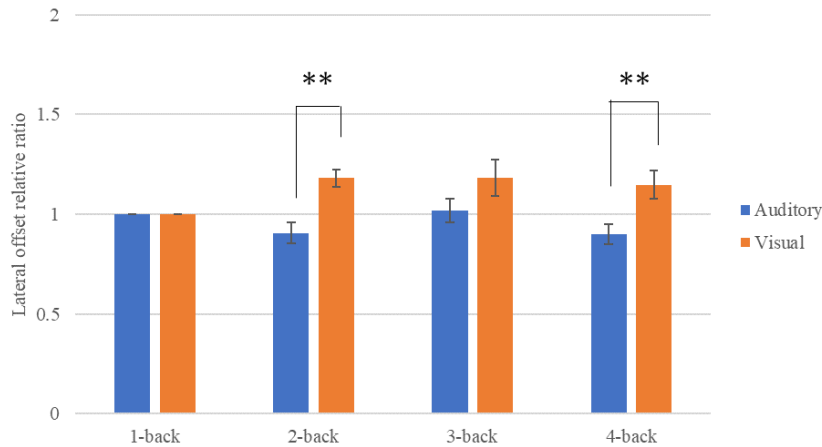


Figure 16. Relative ratio of the amount of lateral offsets in each n-back task with 1-back task as reference.

DISCUSSION

Relationship of Degree of Cognitive Load (N-back Tasks) and Driving Performance

Verification was conducted regarding the influence of cognitive load on driving performance and whether or not there is a moderate degree of load under which performance reaches its highest level.

It was suggested that the influence on steering operation that accompanies increases in the difficulty of auditory n-back tasks is different from the influence on steering operation that accompanies increases in the difficulty of visual n-back tasks. As shown in Fig. 14 and Fig. 15, driving performance in the visual n-back tasks decreased more than in the no n-back tasks. On the other hand, driving performance in the auditory n-back tasks showed no change from the no n-back tasks. However, no tendency for performance to reach its highest level was observed here, either. This is thought to be because differences in the cognitive processing domain result in different influences on driving performance.

Differences in Cognitive Processing Domains and the Relationship with Driving Performance

Verification was conducted regarding whether there is a difference in how driving performance is influenced in separate domains that do not overlap with processing for driving and in the same domain that does overlap with that processing. The result, as shown in Fig. 16, was that the auditory n-back tasks interfered less with steering operation than the visual n-back tasks. Significant differences occurred in the 2-back and 4-back tasks. The n-back task difficulty was more moderate in the auditory 2-back tasks than in the visual 2-back tasks and the subjective effort was higher, and this is thought to be the reason why there was no difference in driving performance between the auditory 2-back tasks and no n-back tasks. There was also the opinion that 4-back tasks were too difficult for the test participants, who therefore gave up on the n-back tasks and gave priority to the driving task. It is conceivable that since the auditory/phonological processing used in the auditory n-back tasks is in a separate domain from the visual/visuo-spatial processing for the driving task, participants were able to concentrate on the driving task so that there was no difference in driving performance from the no n-back tasks.

By contrast, the visual/visuo-spatial processing used in visual n-back tasks is in the same domain as the visual/visuo-spatial processing for the driving task. It is conceivable that for this reason, a simultaneous balance

with the driving task could not be achieved, and so driving performance in the n-back tasks decreased more than in the no n-back tasks. From this, it can be inferred that there are cases when the load from information presentation that employed auditory/phonological processing did not cause driving performance to become unstable, so that there were cases when a simultaneous balance with the driving task could be achieved.

CONCLUSIONS

For this paper, the influence on driving performance from the graded cognitive load of visuo-spatial processing/phonological processing of input from the sense of sight and sense of hearing was studied. As a result, it was found that driving performance changes with the cognitive load. A degree of cognitive load under which performance reaches its highest level was not confirmed, and performance degenerated under the cognitive load from visual/visuo-spatial processing. It was confirmed, however, that under the cognitive load of auditory/phonological processing, which is in a separate domain from the visual/visuo-spatial processing used in driving, there are degrees of load under which performance tends not to change. From this, it was confirmed that there are different tendencies for performance to change according to the type of domain of the load being imposed. It is conceivable that this is because information processes in different domains do not readily influence each other, whereas information processes in the same domain did interfere with each other. In order to maintain stable driving performance, it is conceivably important that the cognitive load imposed on the driver does not interfere with the information from the sense of sight while driving. It may be considered necessary for automobile manufacturers to take the modalities of information equipment into consideration in creating HMIs. As one of the limitations of research, there is the fact that not all processing domains based on the multiple resource model can be examined. It may also be considered necessary to examine the combination of a visual/phonological processing domain and an auditory/visuo-spatial processing domain that does not overlap with the visual/visuo-spatial processing domain that is used in driving.

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