〈Original Article〉

Investigation into the safety of driving by individuals with higher brain dysfunction

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ABSTRACT Dangerous driving by drivers with diseases or disabilities such as dementia, epilepsy, or higher brain dysfunction is viewed as a problem In Worldwide. Given that the majority of such cases of dangerous driving are caused by impairments to cognitive function resulting from these conditions, there is an urgent need to create systems to detect drivers with cognitive functional disability and develop criteria for safe resumption of driving. Because driving would understandably be extremely dangerous for people with higher brain dysfunction, particularly in cases of attention dysfunction, we first examined the correlation between the Clinical Assessment of Attention (CAT), a theoretical task offering an index of attention function, and the cathode ray tube (CRT) driving aptitude test. We then examined correlations between CRT total score and CRT sub-scores. Only the time required for the position Stroop test had a moderate correlation ($r = -0.43$, $p < 0.01$) with CRT total score. Correlations between CRT total score and sub-scores relating to reaction speed showed a strong correlation. Other than reaction speed, items with significant moderate to strong correlations were also seen in the maintenance of moderate mental tension, attention distribution and situation processing skill. The present results show a correlation between CAT score and CRT total score, indicating that CRT total score places relative weights on speed of information processing and suppression of stereotypes, representing a very meaningful result.

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Key words : Driving, Higher brain dysfunction, Cathode ray tube (CRT), Clinical Assessment of Attention (CAT)

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INTRODUCTION

Driving an automobile is an "activities parallel to daily living" (APDL) action that carries enormous weight within our daily living, and is also a vital means of transportation. Particularly in rural areas where public transport networks may not be well developed, driving is often absolutely essential to everyday life, and it has become completely normal for every person to have a car.

Against this social backdrop, dangerous driving by drivers with diseases or disabilities such as dementia, epilepsy, or higher brain dysfunction is viewed as a problem, and is often reported in the media. Given that the majority of such cases of dangerous driving are caused by impairments to cognitive function from these conditions, there is an urgent need to create systems for detecting drivers with cognitive functional disability and also to draw up criteria for safe resumption of driving. This is an extremely important issue, not only to protect the safety of the drivers themselves, but also to ensure the safety of the general public. Although there are presently regulations in place under the Road Traffic Law, there is still an endless succession of tragic accidents as the law is largely ineffective. Cathode ray tube (CRT) driving aptitude test devices that quantify individual attention functions and other driving traits, allowing them to be readily comprehended, have been installed at Driver's License Centers operated by prefectural police forces. In medical settings, however, reference is seldom made to quantifiable evaluation criteria such as neuropsychological tests when approval for driving is given from a medical perspective. Needless to say, this means that the decision whether to allow driving is made without any practical test specialized for driving, such as the CRT driving aptitude test. In other words, the discretion of individual doctors plays a huge part in the decision of whether to allow driving. In clinical settings, approval for driving is given empirically, based on the driver's need for a car due to their living environment and lifestyle pattern, and the doctor's clinical diagnosis. The reality is that tacit consent for driving is given in some cases despite there being some fear that driving may be dangerous.

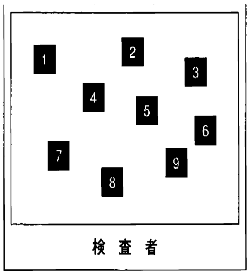
As part of an Okayama Prefectural Government project to widen assistance for patients with higher brain dysfunction and related disabilities, our hospital, which helps many people with higher brain dysfunction, investigated the correlation between a theoretical neuropsychological test and the National Police Agency's CRT driving aptitude test. This basic research was aimed at the formulation of criteria for people with higher brain dysfunction to return safely to driving. Because driving may be considered extremely dangerous for people with higher brain dysfunction, as mentioned earlier, particularly in cases of attention dysfunction[1,2], we first examined the correlation between the Clinical Assessment of Attention (CAT), a theoretical task representing an index of attention function, and the CRT driving aptitude test.

Driving is a dangerous activity requiring various cognitive and motor functions, and a person with impairment of any of these functions should not be deemed fit to drive. Impairments of motor function such as motor paralysis are easy to see, and such people will often cease driving either of their own accord or on the recommendation of their family. However, individuals and their families often fail to spot attention deficits and other cognitive impairments such as those seen in higher brain dysfunction, and some patients who have been advised by their doctor to stop driving decide to resume driving based on their own judgment. This may be because, unlike motor palsy, a driver with even fairly severely impaired attention still has the procedural memory required to drive a car and can therefore perform the operations needed to drive. There is a need to be able to easily and simply detect dangerous drivers with higher brain dysfunction at local healthcare centres. On the assumption that use of the CAT alone is unsuited to such judgments, we examined the correlation between the CAT, as a theoretical index of attention, and the CRT driving aptitude test, as an index of safe driving ability. We then examined the correlations between CRT total score and CRT sub-scores, in order to identify whether the CRT total score was dominated by a particular sub-score.

SUBJECTS AND METHODS

This study was conducted with the approval of the ethics committee of Kawasaki Medical School Hospital (approval no. 1341). Subjects were 18 patients (16 men, 2 women; mean age, 50.3 ± 14.6 years) who had attended the Higher Brain Dysfunction Outpatient Clinic, a specialist outpatient department set up within the Department of Rehabilitation Medicine in Kawasaki Medical School Hospital, between April 1, 2007 and March 31, 2011. Patients were examined by a doctor and completed both the CAT and CRT with no missing values, in order to determine whether they should drive. Subjects also completed the Wechsler Adult Intelligence Scale (WAIS)-III, and all subjects were confirmed to have FIQ (Full Intelligence Quotient) / PIQ (Performance Intelligence Quotient) / VIQ (Verbal Intelligence Quotient) scores ≥ 80 (above the normal), and were confirmed to be free of any symptoms suggesting dementia.

First, we examined correlations between the CAT, a theoretical task that offers an index of attention function, and items in the CRT driving aptitude test related to attention. We then examined correlations



forward ( )桁

( ) 2-5	( ) 6-4
( ) 1-8-3	( ) 4-9-7
( ) 4-2-6-1	( ) 1-6-3-8
( ) 9-5-1-8-2	( ) 7-3-9-4-2
( ) 7-3-9-1-4-6	( ) 6-1-2-5-7-9
( ) 9-5-2-7-1-3-4	( ) 1-3-7-2-8-4-6
( ) 3-6-7-9-1-8-4-5	( ) 9-6-7-2-5-1-3-8
( ) 7-4-5-9-3-8-1-6-2	( ) 5-3-4-9-7-1-6-8-2

backward ( )桁

( ) 9-2	( ) 6-1
( ) 3-7-4	( ) 1-5-8
( ) 2-8-6-1	( ) 4-9-2-7
( ) 4-1-9-2-5	( ) 3-7-5-2-6
( ) 2-1-5-8-9-3	( ) 8-4-2-9-6-3
( ) 8-6-3-1-2-7-9	( ) 6-9-1-7-5-8-4
( ) 3-8-2-7-6-9-4-1	( ) 7-5-2-8-4-3-1-9
( ) 6-3-5-7-1-2-4-9-8	( ) 2-9-7-3-1-6-4-8-5

Fig.1. CAT (Tapping Span forward)
Examiner gives instruction to a patient to copy examiner's example. The examiner taps a sequence of positions on the test paper and the subject must copy the sequence. If patient complete the first row, examiner proceeds to the next row. So, examiner increases digit gradually.

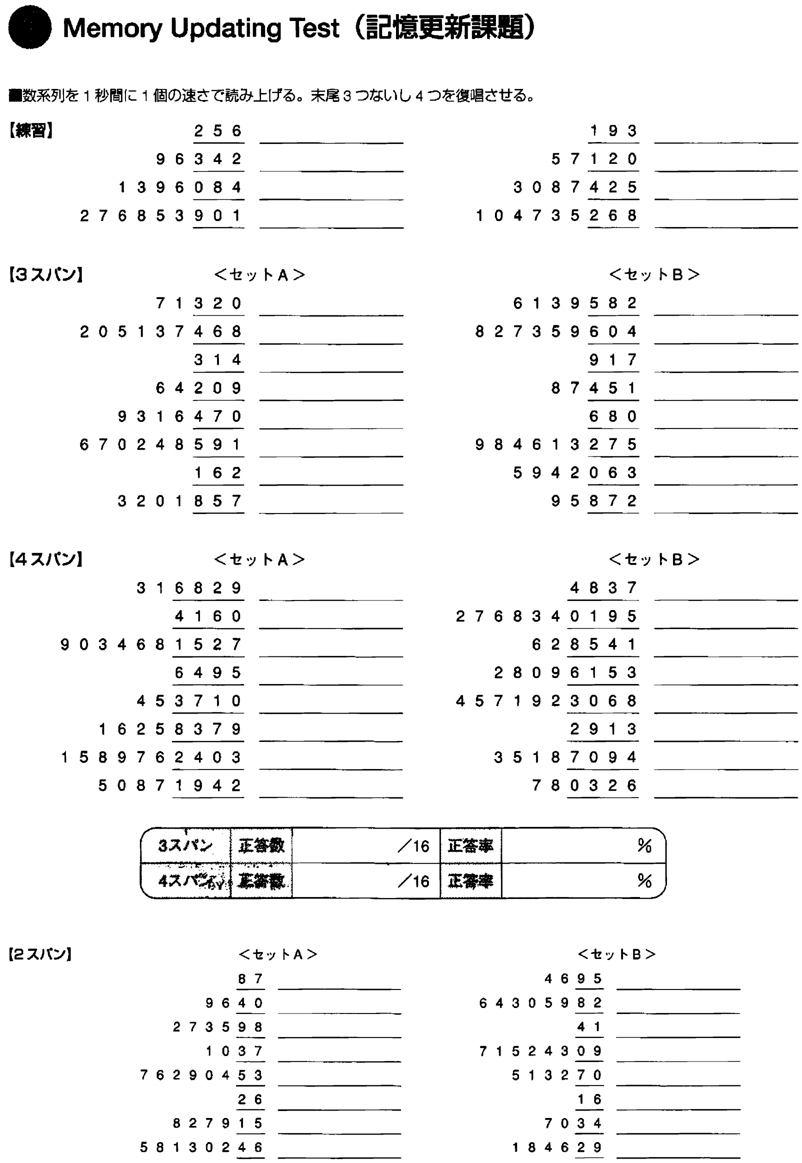


Fig.2. CAT (Memory Updating Test)
Examiner reads some numbers to a patient once a second as directed. Patient has to listen to a series of digits and recalling the three or four most recent digits.

between CRT total score and CAT sub-scores/CRT sub-scores.

The CAT was published in 2006 by the Japan Society for Higher Brain Dysfunction as a battery for the comprehensive assessment of attention, and is currently one of the most widely used attention tests in Japan. The CAT can estimate the attentiveness for which it was difficult to plan by the common linear measure up to now by a standardized system. The construction of CAT consists of 7 tests of Span (assessment of the working memory) (Fig.1) / Cancellation and Detection Test (assessment of

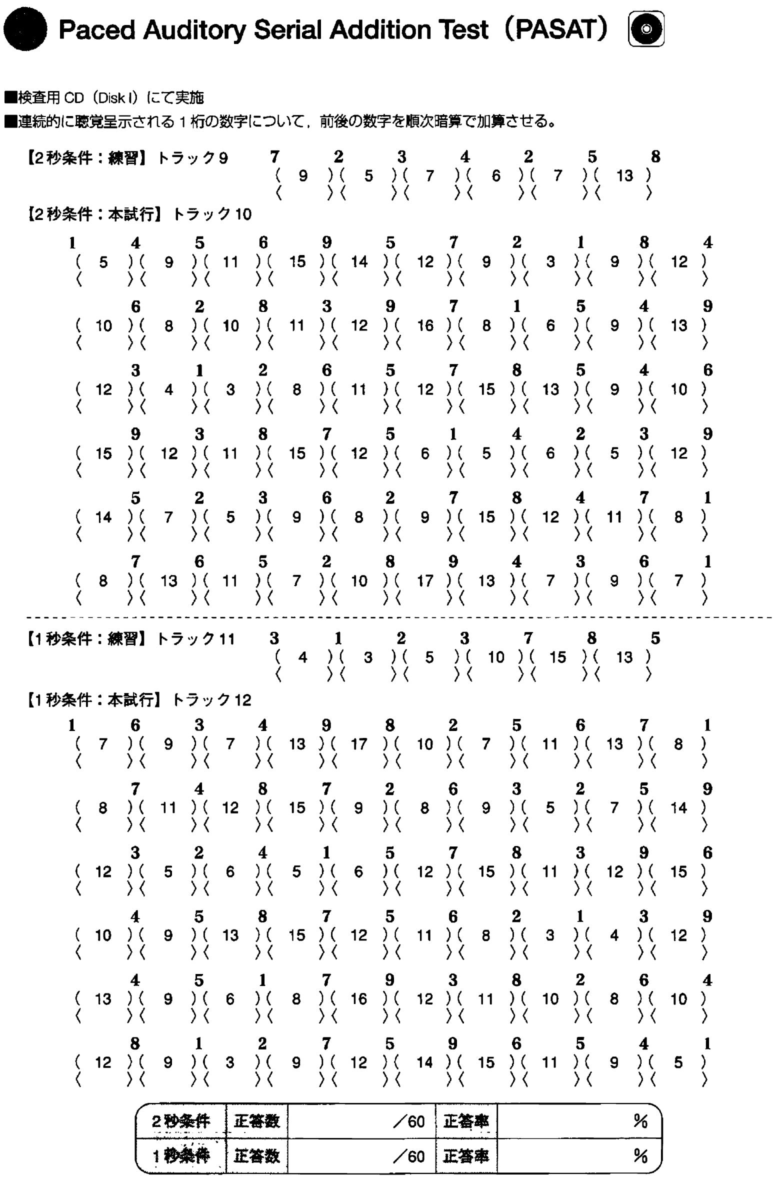


Fig.3. CAT (PASAT)
Examiner uses CD for this test. The PASAT 1/2-s condition presents the numbers at 1/2-s intervals. Patient has to do a sum in patient's head anteroposterior number.

the attention selection) / Symbol Digit Modalities Test (SDMT, assessment of the processing speed and attention distribution) / Memory Updating Test (assessment of the working memory) (Fig.2) / Paced Auditory Serial Addition Test (PASAT, assessment of the working memory and processing speed) (Fig.3) / Position Stroop Test (assessment of the ability to suppress stereotypes and processing speed) (Fig.4) / Simple Reaction Time (X problem/ a AX problem, assessment of the working memory and processing speed and attention selection), and attention various sides can be estimated (Fig5).

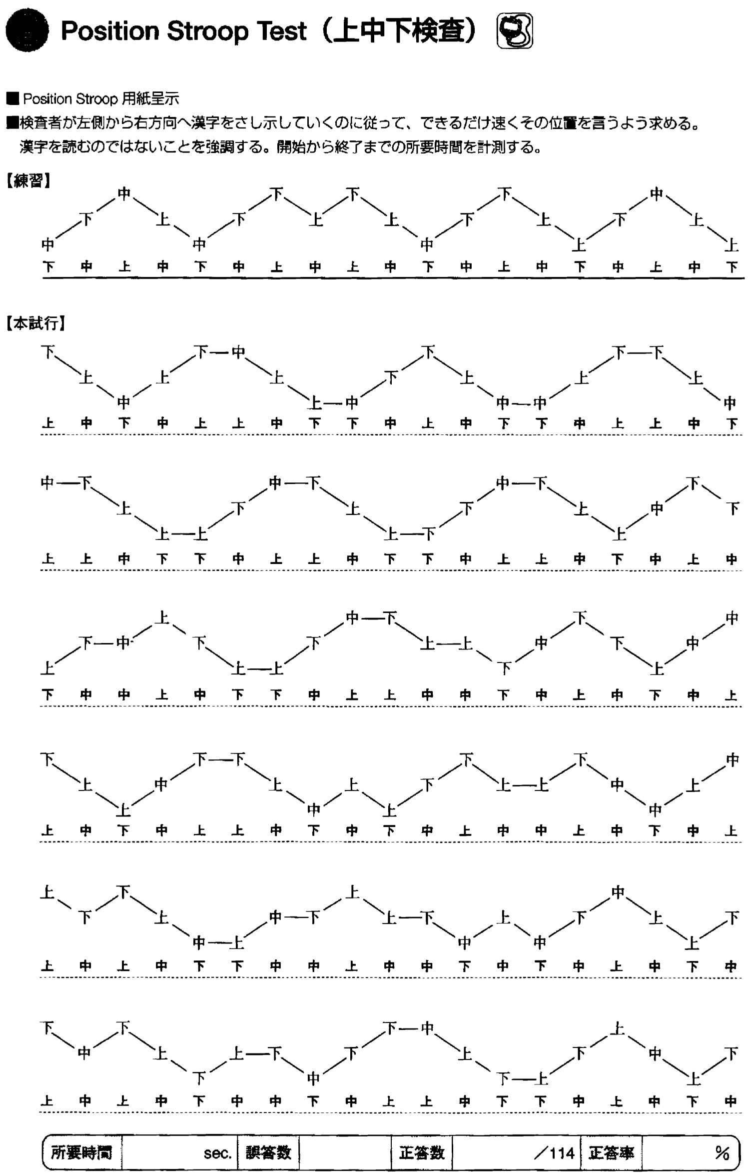


Fig.4. CAT (Position Stroop Test)
The Japanese characters for 'top', 'middle' and 'bottom' are randomly arranged at the top, middle and bottom of the test paper, and the subject must state the position of the character regardless of its meaning.

The CRT test is a computer-based driving aptitude test developed by the National Research Institute of Police Science. This test comprises seven different tests, with driving aptitude being given an overall score of 1 to 5 based on five sub-scores. Although driving performance is evaluated by categories such as handling accuracy, the main focus of the evaluation is cognitive function, with an emphasis on attention, including reaction speed. The test device consists of a display, regulator, left-hand paddle (yellow), right-hand paddle (blue), steering wheel, foot pedals (accelerator, brake), computer,

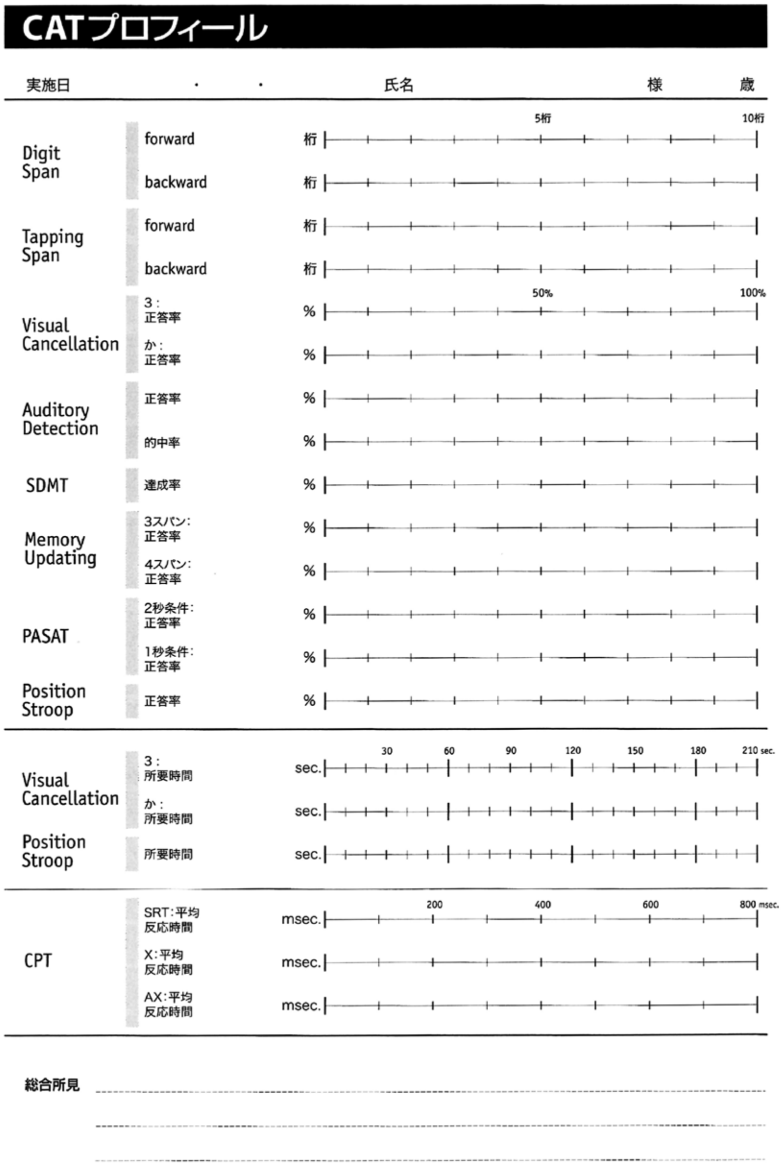


Fig.5. CAT evaluation sheet

printer, IC card reader/writer and a keyboard (Fig.6).

Data were analyzed using JMP10 statistical software (SAS Institute, Cary, NC).

RESULTS

Correlations between CAT and CRT attention items

Correlations between CAT sub-scores and CRT attention items are shown in Table 1. CAT sub-scores showed a middle correlation with CRT attention items. A relatively high correlation was evident between the Paced Auditory Serial Addition Test (PASAT; 1-s condition / 2-s condition) and CRT attention items, with strong correlations ($r = 0.73$ / $p = 0.0005$) between the PASAT 1-s

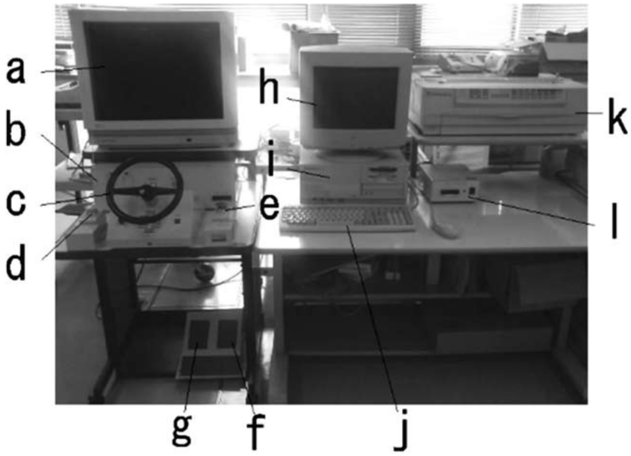


Fig.6. Cathode ray tube (CRT) driving aptitude test devices
a: display b: regulator c: wheel d: left-hand paddle (yellow) e: right-hand paddle (blue)
f: foot pedals (accelerator) g: foot pedals (accelerator) h: computer display for data processing
i: PC for data processing j: keyboard for data processing k: printer l: IC card reader/writer

condition and attention distribution (recognition/dispersion of focus of attention/incorrect reaction/lateral vigilance test/central area/score). In the PASAT 1-s condition, the subject hears a recorded series of single-digit numbers spoken at a rate of 1 number per second and must mentally add the new digit to the preceding one and state the result. This is a particularly demanding CAT task that calls upon working memory and information processing speed. The PASAT 2-s condition presents the numbers at

Table 1. Correlations between CAT and CRT attention items

CRT Subscore Relating to Attention / CAT Score	**Attention distribution/ recognition/dispersion of focus of attention/ mistaken response/ lateral vigilance/all regions/score**	**Attention distribution/ recognition/dispersion of focus of attention/ mistaken response/ lateral vigilance/ central area /score**	**Attention distribution/ recognition/dispersion of focus of attention/ mistaken response/ lateral vigilance reaction /peripheral area/score**	**Attention distribution/ recognition/dispersion of focus of attention/ reaction speed/lateral vigilance test/score**
Tapping Span Forward	R = 0.54 *	R = 0.53 *	R = 0.56 *	
Memory Updating 3 **correct answer rate**	R = 0.55 *	R = 0.61 **	R = 0.54 *	
Memory Updating 4 **correct answer rate**	R = 0.50 *	R = 0.56 *	R = 0.58 *	
PASAT (2sec) **correct answer rate**	R = 0.55 *	R = 0.69 **		
PASAT (1sec) **correct answer rate**	R = 0.55 *	R = 0.70 **		
PositionStroop test **time required**		R = -0.50 *		R = -0.52 *

* $P < 0.05$ ** $P < 0.01$

2-s intervals and can therefore be accomplished with a slightly slower information processing speed than the 1-s condition. Nevertheless, both PASAT conditions have the highest cognitive burden in the CAT. Furthermore, the subject performs 60 additions in each PASAT test and must therefore maintain concentration for 60 s in the 1-s condition and 120 s in the 2-s condition. This means that the tests can be used to assess maintenance of attention despite being only lasting a short time. Looking at other combinations with correlations in excess of r = 0.5 (p < 0.05), performance on CRT attention items tended to correlate with high-burden CAT tests such as PASAT (1-s and 2-s conditions), Memory Updating Test 3/4 (listening to a series of digits and recalling the three or four most recent digits), Tapping Span Forward (the examiner taps a sequence of positions on the test paper and the subject must copy the sequence), Position Stroop test (the Japanese characters for 'top', 'middle' and 'bottom' are randomly arranged at the top, middle and bottom of the test paper, and the subject must state the position of the character regardless of its meaning. This test evaluates the ability to suppress stereotypes). When driving in real life, attention must be distributed to multiple items including direction, dials, physical objects and sounds. While driving, attention must be maintained and cannot falter even for a moment. This requires extremely rapid information processing in accordance with a constantly changing situation. These elements of attention and processing speed are encompassed in the test items that showed high correlation. In summary, the CRT attention tasks were designed to be demanding because driving requires high-level attention, and this is presumably why these tasks correlated with the high-burden CAT test items.

Correlations between CRT total score and CAT

Correlations between CRT total score and CAT sub-scores are shown in Table 2. Only the time required for the position Stroop test showed a moderate correlation (r = -0.43, p = 0.007) with CRT total score. Other than this, tendencies toward correlations with CRT total score were found with variables including Symbol Digit Modalities Test (SMDT) achievement rate (r = 0.47, p = 0.05), Simple Reaction Time (SRT) mean reaction time (r = -0.53, p = 0.09), and Visual Cancellation Δ hit rate (r = -0.46, p = 0.05), although the differences were not significant. These results showed that it is difficult to judge fitness to drive based simply on a single CAT item. However, since many of the CAT items above relate to information processing speed, it appears that information processing speed has a considerable influence on the total CRT score.

Table 2. Correlations between CRT total score and CAT

CRT total score correlation with:	Correlation coefficient
Visual Cancellation Δ : hit rate	R = -0.46
SMDT: achievement rate	R = 0.47
Position Stroop: time required	R = -0.43 **

* P < 0.05 ** P < 0.01

Correlations between CRT total score and CRT sub-scores

Correlations between CRT total scores and CRT sub-scores are shown in Table 3. Among the sub-scores, items relating to reaction speed showed a strong correlation with CRT total score. Other than reaction speed, items with significant moderate to strong correlations were also seen in the maintenance of moderate mental tension (reaction unevenness/continuous emergency reaction test/score, relaxation reaction/continuous emergency reaction test/score), attention distribution (recognition/dispersion of focus of attention/incorrect reaction/lateral vigilance test/central area/score, recognition/dispersion of focus of attention/incorrect reaction/lateral vigilance test/peripheral area/score, recognition/dispersion of focus of attention/incorrect reaction/lateral vigilance test/all regions/score) with CRT total score.

Table 3. Correlations between CRT total score and CRT sub-scores

CRT total score correlation with:	Correlation coefficient
CRT reaction speed/reflex actions/emergency response test/score	R = 0.52 *
Reaction speed/reflex actions/continuous emergency response test/score	R = 0.75 **
Reaction speed/judging action/signal confirmation test/score	R = 0.78 **
Reaction speed/judging action/gas pedal response test/score	R = 0.62 **
Reaction speed/judging action/gas pedal, brake test/score	R = 0.64 **
Maintenance of moderate mental tension/reaction unevenness/continuous emergency response test/score	R = 0.57 *
Maintenance of moderate mental tension/relaxation response/continuous emergency response test/score	R = 0.79 **
Attention distribution/recognition/dispersion of focus of attention/mistaken response/lateral vigilance test/central area/score	R = 0.47 *
Attention distribution/recognition/dispersion of focus of attention/mistaken response/lateral vigilance reaction test/peripheral area/score	R = 0.48 *
Attention distribution/recognition/dispersion of focus of attention/mistaken response/lateral vigilance test/all regions/score	R = 0.56 *

* $P < 0.05$ ** $P < 0.01$

DISCUSSION

The functions and abilities required for safe driving naturally include motor capacities such as absence of paralysis of the arms or legs, as well as the ophthalmological and otolaryngological information-gathering abilities (vision and hearing) of the primary sensory cortex. In addition, higher brain functions, mainly attention, are abilities that are required to the same or an even greater extent. However, surprisingly few studies have focused on driving and higher brain dysfunction[3-6]. While a number of studies have discussed the safety of driving by elderly persons, many have focused on attention functions, as attention functions are well known to decline in the elderly[7-10].

This investigation into attention also revealed information processing speed as a particularly important aspect of attention in the total score for CRT.

Individuals with impairments in any of attention distribution, maintenance, switching or processing speed cannot be considered fit to drive. This is of vital importance not only for protecting the safety of the driver, but also the safety of other members of the public who could potentially become involved in traffic accidents caused by such drivers. The judgment as to whether a person with higher brain dysfunction involving attention impairment should be allowed to drive is of great significance, and it is a judgment that should be made with prudence and fairness. Unfortunately the reality is somewhat different. In practice, in diseases such as cerebrovascular disease in which patients are often left with reduced cognitive function, the decision regarding whether the patient can resume driving normally has to be made from a medical perspective, and a medical certificate is often required. There are currently no tools available to enable fair decisions to be made on an equal basis throughout worldwide, and decisions are made at the discretion of individual doctors on the basis of the Road Traffic Law. However, this law is written in the vague literary style of officialdom. Consequently, many doctors find writing medical certificates a stressful task, and there are occasional cases of doctors who give up altogether on writing certificates. In addition, while more information will obviously permit a more accurate evaluation when the decision is being made, as mentioned before, there are practically no hospitals with CRT driving aptitude test devices or driving simulators installed. Doctors therefore have no option but to make decisions based on very limited information. It would clearly be desirable for doctors, who are already busy with their regular clinical duties, to be able to make decisions on whether a patient can drive as simply and reliably as possible. From this perspective, assuming that overall CRT evaluation correlates with the capacity for safe driving, it would be extremely desirable to make CRT evaluation an index for driving ability. However, no reports have described the relationship between CRT evaluation and safe driving, or the correlation between CRT evaluation and theoretical neuropsychological tests that could be administered by a regular hospital. The present study only used data on a small scale, but is meaningful as it attempted to determine whether the CRT total evaluation score can be estimated in facilities not equipped to carry out the National Police Agency's CRT driving aptitude test, what the overall CRT score actually evaluates, and what cases are judged by the CRT to have high scores. The CAT is a battery of tests that provides an overall evaluation of attention function, and is currently in wide use in Japan. As mentioned earlier, while the CAT is extremely useful in that it can evaluate attention function overall, exactly what attention function (field) is evaluated by each of the test items remains unclear. The present results show a correlation between CAT score and CRT total score, indicating that the CRT total score places relative weights on the speed of information processing and the suppression of stereotypes, representing a very meaningful result.

The limitations of the present study are that the data were on a small scale, in addition to which only the correlation between CRT and CAT was examined, so that correlations of CRT with other general intellectual functions, memory, and executive function are unclear. These tests also lack persuasiveness as materials for judging whether an individual is fit to drive, since correlations between tests and actual driving were not investigated.

We plan to carry out prospective data collection in order to verify whether the trends observed in the present study are indicative of the actual situation. We also plan to test subjects using the HONDA Safety Navi driving simulator as a more realistic driving simulation, and to assess performance in real cars in collaboration with driving instruction centres and prefectural police driver's licence centres.

REFERENCES

1) Nakano K, Park K, Zheng R *et al.*: Leukoaraiosis significantly worsens driving performance of ordinary older drivers. PLOS ONE 9: e108333, 2014.
2) Park K, Nakagawa Y, Kumagai Y, Nagahara M: Leukoaraiosis, a common brain magnetic resonance imaging finding, as a predictor of traffic crashes. PLOS ONE 28: e57255, 2013.
3) Matsuda Y, Katoh N, Okazaki T, Saeki S, Hachisuka K: Evaluation of a simple driving simulation for patients with brain lesions, and its features. JJOMT 56: 102-107, 2008.
4) Yamada K, Sasaki T, Kudo A, Sengoku Y: Relationships between neuropsychological tests and on-road driving assessment for stroke patients. Higher Brain Function Research 33: 270-275, 2013. (Article in Japanese)
5) Tanaka S, Ito E, Sato C, Ochiai Y, Fukui M: Characteristics of driving behaviors and functions in patients with cognitive dysfunction. Sogo Rihabiriteshon 42: 55-462, 2014. (Article in Japanese)
6) Kato T, Suzuki M, Suetsuna T, Inobe J: Applying a drive recorder system to evaluate a driving situation in actual life for patient with higher brain dysfunction. Sogo Rihabiriteshon 37: 961-965, 2009. (Article in Japanese)
7) Caird JK, Edwards CJ, Creaser JI, Horrey WJ: Older driver failures of attention at intersections: using change blindness methods to assess turn decision accuracy. Hum Factors 47: 235-249, 2005.
8) Sekuler AB, Bennett PJ, Mamelak M: Effects of aging on the useful field of view. Exp Aging Res 26: 103-120, 2000.
9) Ishimatsu K, Miura T, Shinohara K: Age influences visual attention characteristics among accident-free and accident-involved drivers. Japanese Psychological Research 52: 186-200, 2010.
10) Ishimatsu K, Miura T: Divided attention and aging. Japanese Psychological Review46: 314-329, 2003. (Article in Japanese)