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Detecting General and Memory-specific Cognitive Impairment Using Balance and Sensory Parameters

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The objective of this study was to find variables that showed significant associations with cognitive decline and memory loss in visual, auditory, olfactory, and balance functions. Seventy-six elderly people aged 65 or older participated in the experiment, received the aforementioned functions' assessments, and underwent cognitive screening. Participants were divided into the normal cognitive (NC) and lower cognitive (LC) groups on the basis of cognitive function test scores, and the LC group was divided into the lower-MIS and normal-MIS groups on the basis of memory index scores (MISs). The LC group had less balance, hearing, and olfactory functions than the NC group, and the lower-MIS group had less visual and auditory functions than the normal-MIS group. The performance of the classification model made of variables was evaluated as the area under the receiver operating characteristic curve. The performance was shown to be good. Therefore, this study can be the basis for the development of tools for the early diagnosis of dementia and the creation of a smart environment.

1. Introduction

According to the World Health Organization's Global action plan for the public health response to dementia 2017–2025, dementia affected 47 million people worldwide in 2015, a number that is expected to reach 132 million by 2050.(1) Currently, dementia is mostly treated with medication. The medication is designed to slow the progression of dementia, improve the cognitive function of dementia patients, and alleviate symptoms. In other words, dementia treatment cannot completely prevent the progression of dementia.(2) Since dementia makes it difficult to return to normal cognition once it occurs, it cannot be effective if treated after progressing. However, in the early stage of cognitive impairment, it is possible to improve the

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cognitive function through intervention.[3] Therefore, detecting and intervening in the early stage of cognitive impairment will prevent the progression to dementia.

Mild cognitive impairment (MCI), considered a precursor to dementia, refers to an early stage of memory loss but the ability to do daily life activities is maintained. Approximately 18% of older adults with MCI are known to progress to dementia within a year.[4] It is important to identify MCI because people with MCI progress to dementia and for the aforementioned reasons. According to a study by Petersen,[5] depending on whether memory loss is present, there are subtypes of MCI: amnestic MCI (aMCI) and non-amnestic MCI (naMCI). aMCI is considered a precursor of Alzheimer's dementia (AD), which causes symptoms such as amnesia and visual dysfunction due to the degeneration of the anterior frontal lobe.[5] Although naMCI reportedly showed memory conservation, it is also reported that language, visuospatial, and frontal/executive functions are degraded and considered precursors of Lewy body and frontotemporal dementia.[5] As previously mentioned, aMCI is considered a precursor of AD. However, to diagnose aMCI, brain imaging techniques that observe changes in brain volume[6] or brain function network analyses[7] are used. Because these methods are complex and costly, they prevent early detection. Therefore, it is necessary to find diagnostic methods that can be widely used by employing easily obtainable variables.

As a way to solve the aforementioned issues, sensory and balance functions have been measured because they are associated with cognitive decline and dementia. Schubert *et al.* reported that people with hearing, visual, and olfactory disorders had a lower cognitive task ability than those without.[8] Bigelow and Agrawal reported that vestibular function is associated with various cognitive functions as well as visuospatial abilities and attention areas.[9] Deal *et al.*[10] and Paik *et al.*[11] reported that dementia patients had visual and hearing dysfunction. Therefore, sensory and balance functions can be used to detect MCI. Anwar *et al.* also proposed the integration of microwave sensors and hearing aids for the early detection of dementia.[12] Shende *et al.* monitored the daily lives of dementia patients and detected falls with IoT technology.[13] Müller *et al.* investigated sensory and balance functions for the development of sensor-based systems for the early detection of dementia.[14] Previous studies demonstrated the possibility of the early detection of the dementia precursor stage through sensory and balance functions, so these functions can also be used to distinguish between aMCI and naMCI as subtypes of MCI.

The purpose of this study is to investigate the possibility that sensory and balance functions can be used as tools for predicting MCI and aMCI. We examined balance and sensory functions to explore the function differences between groups classified as having cognitive decline and memory decline, and to evaluate the performance of discriminant analysis models comprising them.

2. Methods

2.1 Participants and procedure

A total of 76 elderly men aged over 65 participated in this study. Only those who can complete tasks independently were recruited. The study's purpose, content, methods, procedures, risks, and benefits were explained verbally and in writing to the participants, who then provided their written informed consent to participate in this study. We examined the participants' height, weight, medical history, intensity and frequency of exercise, and frequencies of drinking and smoking. Participants provided their age and years of education as well. The experiment required two visits. On the first visit, a cognitive function test was performed. The second visit involved auditory, visual, balance, and olfactory function tests. This study was conducted with the approval of Jeonbuk National University IRB (JBNU IRB File No.2022-04-017-003).

2.2 Cognitive function test

The participants' cognitive function was measured using the Korean Version of Montreal Cognitive Assessment (K-MoCA). From the results of the test, the participants were divided into the normal cognitive (NC) and lower cognitive (LC) groups on the basis of a cutoff of 26 points.[15] In the LC group, the participants were divided into the lower-MIS and normal-MIS groups on the basis of a cutoff of 7 in the memory index score (MIS) among the MoCA indexes. The MoCA-MIS ranges from 0 to 15 and is determined by summing the words remembered in free delayed recall, category-cued recall, and various-choice-cued recall multiplied by 3, 2, and 1, respectively.[16]

2.3 Auditory function

In the auditory function test, Korean speech audiometry tests and an audiometer (GSI-61, Grason-Stadler, Denmark) with a recorded sample were used. Participants put headphones in a soundproof chamber. Pure tone audiometry (PTA) assessed the ear on the one side with good hearing first; if there was no difference in hearing between both ears, the test was performed from the right ear. The word recognition score (WRS) test shows the percentage of how accurately the participant recognizes and listens to monosyllabic words at a participant's most comfortable level that is easy to hear. PTA and WRS were used in the analyses. The explanations of the variables used are presented below.

1. PTA_AVG = Average pure tone audiometry (PTA) dBHL at 500, 1000, and 2000 Hz
2. WRS_AVG = Average word recognition score (WRS) of both ears
3. WRS_B = Better WRS between both ears
4. WRS_NE = Number of errors on word recognition test

2.4 Visual function

For the visual function measurement, Jin's vision chart was used to evaluate visual acuity and the Lea Numbers 10M Flip chart (LEA TEST INTL, LLC., Pennsylvania, USA) was used to evaluate contrast sensitivity (CS). Participants wearing glasses measured their visual acuity both with and without glasses. The Lea Numbers chart has five numbers on one sheet of the contrast test table, which consists of five sheets. The number of correct answers among the 25 gradually brighter numbers at distances of 1.6, 2, 3, and 4 m was recorded. The explanations of the variables used are presented below.

1. Visual acuity uncorrected = Average visual acuity when all participants were not wearing glasses
2. CS uncorrected = Average CS score when all participants were not wearing glasses

2.5 Balance function

For the balance function measurement, the Biodex Balance System (Biodex Medical System. Inc., Smithtown, NY, USA) was used to evaluate the postural stability and limits of stability (LOS). Postural stability measurement consists of three trials of 20 s with a 10 s break time in each trial. Participants were standing still comfortably on the foot platform with their eyes open and closed. LOS measurement also consists of three trials. During each trial, participants shifted their bodies to move the cursor from the center target to a blinking target and return as quickly and as straight as possible. The same process is repeated for each of the nine targets. The explanations of the variables used are presented below.
1. MLSI_EO = Average of mediolateral stability index (MLSI) when eyes are open
2. MLSI_EC = Average of MLSI when eyes are closed
3. LOSTIME = Average time to complete trials of LOS
4. BACK_LEFT = Accuracy score of the backward-left movement to the blinking target in LOS trial

2.6 Olfactory function

For olfactory function measurements, the Snap & Sniff® olfactory test system (Sensonics International, Haddon Heights, NJ, USA) was used to evaluate threshold, odor identification, and odor discrimination. The threshold test evaluated the sensitivity of a participant's nose. A participant smells two odors with different intensities and chooses which odor feels stronger. If the participant chooses a strong odor, the participant will smell two odors that do not differ much in intensity, and if not, the participant will smell two odors that have a large difference in intensity. The odor identification test is a test that involves smelling a total of 16 odors and guessing what the odor is. Four choices are given for each odor. The odor discrimination test assessed the ability to differentiate between different odors. In each of the 22 trials, the participant is asked to choose which of the three odors is different from the other two. The administration time of the test varies slightly, depending on the ability of the participant. The number of correct answers was used as a variable.

2.7 Analysis

In all data sets, NC and LC and lower-MIS and normal-MIS were compared using the Mann–Whitney test. After confirming variables representing significant differences between the two groups, discriminant analysis was performed in the training set with the variables, and the predictive ability of the created linear discrimination function was examined from the test set to the receiver operating characteristic (ROC) curve. The 95% confidence interval and the area under the curve (AUC) were examined by ROC curve analysis.

Statistical analysis was carried out utilizing the IBM Statistical Package for the Social Sciences (SPSS) version 26.0. All results are reported in the format MEAN ± SD with SD representing standard deviation. A training set and a test set were created out of all the data sets at a ratio of 60:40.[17]

3. Results

3.1 Demographics

Of the 76 participants, 31 were classified into the NC group and 45 into the LC group. Of the LC group, 20 were classified into the lower-MIS group and 25 into the normal-MIS group. The differences in demographic characteristics between groups are shown in Table 1.

3.2 Participant's health

Table 2 shows the survey results of the participants' medical history. A significant difference between the NC and LC groups was found only in terms of whether they had cataract surgery. In the NC group, 67.74% of the participants had cataract surgery, whereas in the LC group, 42.22% had cataract surgery.

3.3 Significant sensory parameters

Table 3 shows the variables with significant differences between the NC and LC groups. Significant variables were found in the case of balance, hearing, and olfactory functions.

Table 4 shows the variables with significant differences between the lower-MIS and normal-MIS groups. Significant variables were found in the case of visual and hearing functions.

3.4 Classification models

Table 5 and Fig. 1 present the AUC and ROC values of the discriminant analysis models 1 and 2, respectively. Model 1 detects LC between NC and LC. Model 2 detects lower-MIS between normal-MIS and lower-MIS. Model 1 consists of variables in Table 3 and cataract surgery in Table 2. Model 2 consists of variables in Table 4. The AUC of model 1 was 0.787 in a 95% confidence interval. The AUC of model 2 was 0.840 in a 95% confidence interval. The models' p-value was below 0.05.

4. Discussion

In this study, significant differences in sensory and balance functions by group were examined, and the classification performance of discriminant analysis models made of sensory and balance function variables having significant differences was verified with ROC. As a result of the study, there were significant differences in balance, hearing, and olfactory functions between NC and LC, and NC's ability was better than LC's. There were significant differences

Table 1
Demographic characteristics.

	NC (n = 31)	LC (n = 45)	
		Lower-MIS (n = 20)	Normal-MIS (n = 25)
K-MoCA score	27.42 ± 0.63	21.15 ± 1.30	23.28 ± 0.71
Delayed recall score	13.19 ± 0.98	5.55 ± 0.79	11.12 ± 0.82
Age (years)	74.84 ± 1.97	78.45 ± 2.06	75.48 ± 1.77
Height (cm)	165.76 ± 2.83	165.66 ± 3.02	165.90 ± 2.60
Weight (kg)	66.46 ± 3.51	66.19 ± 4.39	68.63 ± 4.51
Education (years)	15.16 ± 1.05	13.05 ± 1.67	11.12 ± 0.82

MoCA: Montreal Cognitive Assessment, NC: Normal Cognitive, LC: Lower Cognitive, MIS: Memory Index Score

Table 2
Each groups' medical history.

	NC (n = 31)	LC (n = 45)	
		Lower-MIS (n = 20)	Normal-MIS (n = 25)
Diabetes	51.61%	50.00%	32.00%
Asthma	0%	5.00%	4.00%
Hypertension	48.39%	45.00%	48.00%
Cardiovascular issue	16.13%	20.00%	28.00%
Neurovascular issue	0%	10.00%	8.00%
Hyperlipidemia	22.58%	30.00%	28.00%
Hearing issue	25.81%	30.00%	40.00%
Cataract Surgery**	67.74%	45.00%	40.00%

**: $p < 0.05$, NC: Normal Cognitive, LC: Lower Cognitive

Table 3
Significant variables in balance, hearing, and olfactory functions.

	NC (n = 31)	LC (n = 45)
MLSI_EO**	0.18 ± 0.15	0.22 ± 0.13
MLSI_EC*	0.56 ± 0.48	0.72 ± 0.48
LOSTIME**	50.89 ±12.30	63.09 ± 19.25
BACK_LEFT**	33.96 ±15.01	25.08 ± 12.13
PTA_AVG*	24.97 ± 13.29	30.27 ± 12.30
OLF_DIS**	13.50 ± 3.29	11.54 ± 3.42

*: $p < 0.1$, **: $p < 0.05$, NC: Normal Cognitive, LC: Lower Cognitive,
MLSI: Medial-Lateral Stability Index, LOS: Limits of Stability, PTA: Pure Tone Audiometry, OLF-DIS: Olfactory Discrimination Score

Table 4
Significant variables in visual and hearing functions.

	Lower-MIS (n = 20)	Normal-MIS (n = 25)
Visual acuity uncorrected*	0.62 ± 0.23	0.77 ± 0.24
CS-4m uncorrected**	5.95 ± 5.77	10.83 ± 5.91
CS-3m uncorrected**	11.44 ± 6.31	15.46 ± 5.15
CS-2m uncorrected**	15.44 ± 6.26	20.67 ± 4.46
CS-1.6m uncorrected**	19.24 ± 4.10	23.42 ± 2.64
WRS_AVG*	70.00 ± 15.18	77.23 ±15.26
WRS_B*	76.25 ± 15.18	81.67 ± 15.01
WRS_NE*	14.94 ± 7.63	11.38 ± 7.61

*: $p < 0.1$, **: $p < 0.05$, MIS: Memory Index Score, CS: Contrast Sensitivity, WRS: Word Recognition Score

Table 5
AUC values of discrimination models 1 and 2.

	AUC	Standard Error	*p*	95% Confidence Interval	
				Upper limit	Lower limit
Model 1	0.787	0.088	0.008	0.614	0.960
Model 2	0.840	0.102	0.018	0.640	1.000

AUC: Area Under the Curve

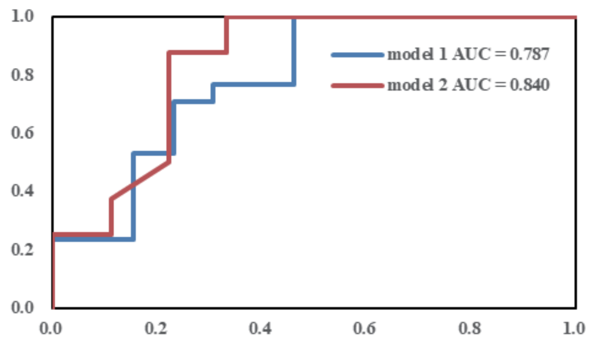

Fig. 1. (Color online) ROC values of discrimination models 1 and 2.

in visual and hearing functions between lower-MIS and normal-MIS, and normal-MIS's ability was better than lower-MIS's. It was confirmed that models 1 and 2 exhibit classification performance of more than 75%. Both models were statistically significant because the *p*-value was below 0.05.

The number of those who underwent cataract surgery is higher in the NC group than in the LC group. Visual impairment is related to cognitive function deterioration;[18] the participants' cognitive function is normal, but there is also a study showing that visual impairment can degrade cognitive performance.[19] As mentioned earlier that the cognitive function may be deteriorated on account of visual impairment, it can be expected that the cognitive function can also be improved if cataract surgery improves visual impairment. A previous study has shown that people who did not have cataract surgery are more likely to have MCI than those who had cataract surgery, and the result of our study is consistent with this.

The MLSI value of the LC group was found to be larger than that of the NC group both when the eyes were open and closed. The larger the value, the more body swaying, and the results of the study mean that the LC group has more movement in the mediolateral than the NC group when standing still. In addition, it has been reported that there is more mediolateral swaying in the mild cognitive impairment group than in the normal cognitive group.[20] LOS is a stability variable that evaluates the balance function by providing information on motor control in a dynamic state. In addition, a participant's poor control and increased times to complete the LOS test suggest vestibular deficiency. The LC group had a longer measurement time than the NC group, and the backward-left movement was found to be poor. A previous study has shown that people with vestibular disorders are 3 to 4 times more likely to have MCI than those who do not.[21] Therefore, a decrease in balance function can be an indicator of a decrease in cognitive function.

As a result of PTA, the threshold of the LC group was found to be higher than that of the NC group. The measurement results of the two groups were 30.27 dBHL for LC and 24.97 dBHL for NC. This indicates that the LC group has a lower auditory ability than the NC group. Hearing loss appears in people with dementia and the elderly with cognitive impairment.(22) According to a previous study, a greater decrease in cognitive function can be observed in those with hearing impairment.(23)

The olfactory discrimination score of the LC group was inferior to that of the NC group. That is, the discrimination score can be utilized as a maker to discern between NC and LC. Olfactory function impairment was reported as an early symptom of neurodegenerative disease.(24) Cognitive decline is an early symptom of neurodegenerative disease, so olfactory dysfunction was found to occur alongside mild cognitive impairment.(25) In particular, disorders in odor discrimination can predict cognitive decline.(26) Therefore, the findings in the present study are in accordance with previous research.

CS scores represent the ability to detect subtle differences in shading. The CS scores of the lower-MIS group were lower than those of the normal-MIS group. In other words, the participants with memory impairments presented with a lower contrast sensitivity, which is consistent with the previous study,(27) as contrast sensitivity defects have been observed in patients with AD. The visual acuity of the lower-MIS group was lower than that of the normal-MIS group. However, since the visual acuity of the lower-MIS group exceeds 0.3, it corresponds to normal visual acuity. Although it is known that rapid visual acuity loss occurs in Alzheimer's patients, studies show that visual acuity is measured normally in the early stages of Alzheimer's.(28) Since aMCI is a precursor to Alzheimer's, visual acuity in the lower-MIS group is normal.

WRS represents the ability to accurately hear single syllables at a level appropriate for listening. The WRS of the lower-MIS group was lower than that of the normal-MIS group. Since low WRS has been observed in Alzheimer's patients, WRS was found to be low in the group with memory impairments as a result consistent with a previous study.(29)

The ROC curve was used to evaluate the usefulness of the classification models made of variables with significant differences. The usefulness can be measured using the AUC value, which means that the closer to 1, the more perfect the test is. If the AUC is 0.7–0.8, it is considered acceptable discrimination. If the AUC is 0.8–0.9, it is considered excellent discrimination.(30) If the AUC exceeds 0.9, it is considered outstanding discrimination. The AUC of classification model 1 is 0.787 and that of model 2 is 0.840, indicating that these classification models can classify the LC and lower-MIS groups well. It can also be regarded that our models are valuable because the p-values are less than 0.05.

These are the study's limitations: (1) small number of participants—increasing the number of participants can result in a better classification; (2) few participants who are diagnosed clinically—a study performed with participants confirmed to have a certain type of MCI will give more insight into the application of sensory functions for diagnostic purposes. However, as previously mentioned, not many older individuals receive a diagnosis owing to the difficulty of the diagnostic process.

5. Conclusions

This study was performed to determine whether balance and sensory functions are useful in detecting cognitive decline and cognitive decline with memory loss. Participants with low cognitive function underwent less cataract surgery, had more mediolateral swaying when standing, required more time to move the center of gravity, had a high risk of falling when shifting their bodyweight backward-left, had low hearing sensitivity, and did not distinguish well between different smells. Also, participants with low MIS had low visual acuity, were unable to identify objects with unclear boundaries, and had poor ability to listen and repeat monosyllables accurately.

The classification models show that the combination of participants' medical history, balance, hearing, and visual and olfactory function variables can help diagnose cognitive decline and aMCI. Model 1 consists of Cataract Surgery, MLSI_EO, MLSI_EC, LOSTIME, BACK_LEFT, PTA_AVG, and OLF_DIS variables, and its AUC that detects LC is 0.787. Model 2 consists of visual acuity uncorrected, CS-4m uncorrected, CS-3m uncorrected, CS-2m uncorrected, CS-1.6m uncorrected, and WRS_AVG, WRSB, and WRS_NE variables, and its AUC that detects aMCI is 0.840.

These findings suggest that balance and sensory function can be used to discover the elderly with cognitive deterioration and memory decline cognitive impairment. This can have the potential for a diagnosis using balance and sensory function whereby the elderly feels less pressure in relation to the cost of dementia tests.

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