Article

"Now" Behavioral Patterns in Elderly Dementia with Cognitive, Motivational, and Emotional Dysfunction: Analysis of Behavioral Patterns Using Network Analysis Based on Graph Theory

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ABSTRACT

Background: The method to understand the "now" behavior of dementia patients is based on direct behavioral observations. However, in Japan there are a limited number of trained professionals capable of performing direct observations. This study aimed to classify patients with dementia into high and low mental function groups on the basis of the cognitive, motivational, and emotional functions of the Mental Function Impairment Scale, and to visualize the behavioral patterns in each group using sensing technology as an alternative to direct observations.

Methods: We classified participants' cognitive, motivational, and emotional functions into high and low mental function groups and analyzed the characteristics of each group's behavioral patterns using a network analysis based on graph theory. Location information collected by wearing a sensor wristband (Fujitsu's ubiquitous software) was used to analyze behavioral patterns, and the Mental Function Impairment Scale was used to assess cognitive, motivational, and emotional functions.

Results: The behavior of those with low cognitive functioning showed a uniform behavioral pattern, and those with low motivational and emotional functioning were considered to be in a state where the behavior itself could not be generated.

Conclusions: The sensor technology accurately reflected the behavioral patterns of the high- and low-value groups across each of the three MENFIS sub-items, cognitive function, motivational function, and emotional function. Individuals with low cognitive function showed a

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uniform, stationary behavioral pattern, indicative of executive function deficits.

KEYWORDS: graph theory; dementia; pattern of behavior

ABBREVIATIONS

MENFIS, Mental Function Impairment Scale

INTRODUCTION

The analysis of behavioral patterns in dementia and the implementation of behavior analytic interventions have contributed to reducing the behavioral and psychological symptoms of dementia (BPSD) [1–4]. In behavior analysis, “behavior” mainly implies to operant behavior, which refers to behaviors which are modified by behavioral accompaniment (preceding stimulus-behavior-following stimulus) in which the frequency of occurrence of the following behavior alters with changes in the environment [5]. “Behavior” is any activity that actively interacts with the environment and includes not only behaviors observed by others, but also thoughts and feelings [5]. In addition, behavior analysis targets behaviors that are focused on the “now.” For example, in the case of dementia, we can ask, “Why are cognitive symptoms occurring frequently now?”, “Why is the patient not presenting with cognitive symptoms now?”, or “What should we do to change cognitive symptoms into desirable behaviors in the future?” These questions are analyzed on the basis of the principle of behavioral concomitants, and appropriate remedial measures are developed and implemented as required [5].

The method to understand the “now” behavior of dementia patients must be based on direct behavioral observation [6]. In other countries, many professionals such as clinical psychologists have been trained to directly observe the behavior of elderly people with dementia. In Japan, however, trained professionals capable of direct observation are limited, necessitating alternative methods to evaluate the behavior of people with dementia.

One approach to solve this problem is through sensing technology, which uses devices and equipment to gather the information required to present actual data. In recent years, technology has been developed to connect sensors and sensing technology through the “Internet of Things” and to quantify sensing data in the cloud, and this technology is now available to the general public. In addition, visualization of sensing data can prevent information overflow caused by large amounts of data, making it easier to understand and manipulate the information. For example, attachment of a sensor to an elderly person with dementia, collection of the information output from the sensor for a specific period of time, and visualization of the quantified behavior can improve our understanding of the “now” behavior of the person with dementia.

Dementia causes impairment of overall cognitive functioning, including thought (cognition) and emotional (motivation, mood, etc.) disorders, and the accompanying “behaviors” impose a great burden on both the dementia patient and their caregivers. Previous studies have discussed symptoms and behaviors which occur in patients with dementia that make caregiving difficult, as typified by BPSD, but few previous studies have considered the meaning of these behaviors. The Mental Function Impairment Scale (MENFIS) is an assessment method that can evaluate cognitive function in dementia from the perspective of thinking (cognition) and feeling (motivation, mood, etc.). The MENFIS assumes that mental dysfunction in dementia is an impairment of three main functions (cognitive, motivational, and emotional functions), and uses three subscales (13 items) to evaluate these functions independently [7]. An understanding of the “now” behaviors of dementia patients with cognitive, motivational, and emotional deficits can provide basic data for implementing behavior analytic interventions. However, the characteristics of the behavioral patterns caused by impairments in these functions have not yet been clarified.

This study aimed to classify dementia patients into high and low mental function groups in each of the three sub-items of the MENFIS (cognitive, motivational, and emotional functions), visualize the behavioral patterns of each group, and clarify the characteristics of the “now” behavior of dementia patients with impairments across these three affective functions.

MATERIALS AND METHODS

Participants

The subjects were 16 women diagnosed with Alzheimer’s disease (AD) who were receiving day care at a day care center in City A. The inclusion criteria were as follows: (I) aged 65 years of age or older; (II) ability to walk unassisted; and (III) a diagnosis of AD confirmed by a family doctor with a score of 20 or less on the revised Hasegawa simple intelligence rating scale (HDS-R). The exclusion criteria were as follows: (I) those who had difficulty communicating; (II) those diagnosed with cerebrovascular disease; (III) those who had a history of dementia with Lewy bodies or frontotemporal dementia; and (IV) those who had a history of depression. In this study, we limited the sample to AD patients to derive disease-specific empirical classifications of behaviors when disease-specific symptoms were strongly reflected in the behavioral patterns.

This study was conducted with the approval of the Research Ethics Committee of Kansai Medical University (No. 18-32, Approval date: April 5, 2021) and conformed to the tenets of the Declaration of Helsinki. Written informed consent for the research has been obtained from participants.

Evaluation Details

MENFIS was used to evaluate mental functions in dementia, and Ubiquitous Ware developed by Fujitsu Limited was used to measure the behavioral patterns [7]. MENFIS is a mental function assessment scale that was developed in Japan to assess the severity of core symptoms in dementia and the elderly. It can be used to assess a wide range of individuals, ranging from healthy elderly people with normal intellectual functioning to those with advanced dementia that cannot be assessed by other testing methods. MENFIS assesses the severity of cognitive, motivational, and emotional dysfunction in dementia and calculates the overall disease severity by summing the scores. The evaluation is performed using seven items assessing cognitive function, three items assessing motivational function, and three items assessing emotional function, each of which is rated on a 7-point scale from 0 (no impairment) to 6 (complete impairment), with higher scores indicating more severe impairment. The developers of MENFIS have already reported its parallel validity, clinical validity, and inter-rater validity [7].

Ubiquitous Ware

Ubiquitous Ware consists of a core module that combines a gyroscope and microphone with sensors to measure acceleration, barometric pressure, and geomagnetism. It is a Bluetooth Low Energy-enabled wireless dedicated microcontroller that directly controls and analyzes the sensors, and works in tandem with Fujitsu's original middleware that learns and analyzes data on the cloud side. The middleware can convert the data collected from the sensor devices into location information of people and objects within a set indoor and outdoor range. These data are analyzed using Fujitsu's proprietary algorithms to quantify activity and energy consumption based on the people’s movements to understand the body posture and state when in a standing, sitting, and lying position, and to obtain trajectory data pertaining to behavior by estimating the distance and direction based on the movement characteristics. For details, please refer to the website of Fujitsu Limited [8].

In this study, a wristwatch-type vital sensing band was used as the core module. All measurements were conducted in a day room that is mainly used by Nursing Home users. This room is used for conducting various recreational activities, eating, and resting, and is equipped with a television for viewing. There is also a staff room and restrooms nearby. The room was divided into nine areas at 6-meter intervals, and a beacon was placed on the ceiling at the center of each area. The radio wave transmitted from the beacon was received by the vital sensing band that passed underneath the beacon, and the data were analyzed on the cloud. The beacon number was output every three seconds and comprised location information which indicated which beacon area the user was in.

These location data were stored as the user's sensing data during the time of use. On the day of use, the vital sensing bands were randomly distributed to users who had given their consent, and the users were asked to wear them at all times except while bathing. The vital sensing bands were managed by the nursing staff in a roster to avoid repeatedly distributing them to the same users. Five days of data, collected from Monday to Friday, were obtained over four weeks.

Analytical Methods

In this report, MENFIS was used to assess mental function in dementia, while behavioral data of 81,867 rows for 16 persons with one vital sensing band were used for analysis. The sensing data used in the analysis were the beacon numbers that were output as location information every three seconds.

For the analysis, first, the median of each of the cognitive, motivational, and emotional function scores of the MENFIS was calculated and used to classify the patients into high- and low-value groups. Next, to analyze the behavioral patterns of the high- and low-value groups, the most frequent values of beacon number output every three seconds were calculated, and an adjacency matrix was created based on the number of times the vital sensing band moved between beacons, followed by network analysis based on graph theory. In other words, we performed a network analysis based on the number of times a participant moved between beacons. The network analysis based on graph theory focused on the number of connections between elements (nodes), and the betweenness centrality of each element was analyzed [9]. In this report, beacons are set as nodes, and the betweenness centrality indicated which beacon was the main mediator. In the visualized graph, beacons acting as "hubs" with high betweenness centrality values are indicated by the size of the circle. In addition, the clustering coefficients of the high- and low- value groups were calculated. The clustering coefficient is a measure of the density of a given network characterized by tightly connected clusters of nodes. The density of this network is interpreted as the diversity of the behavior. Thus, the clustering coefficient was used as an indicator of behavioral diversity. For statistical analysis, NodeXL (NodeXL basic version) was used for network analysis based on graph theory, which was used to visualize the location information.

An interdisciplinary team comprising six occupational therapists, one physical therapist, and two nursing staff interpretated the behavioral patterns. During the consultation, we used the method of polarity comparison, in which we always assumed the opposite situation to the interpretation proposed by the researcher and checked the data for its existence. This approach confirmed the maximum possible range of the phenomenon and the maximum allowable range of interpretation and allowed assessment of the danger of unintentional interpretation in a certain direction by the researchers [10]. Conceptualization of the behavioral patterns was performed by the occupational and physical therapists, and the daily situations were added to the behavioral patterns by the nursing staff. These discussions were repeated until logical saturation was reached.

RESULTS

A total of 56 participants were enrolled in this study. Of these, 40 were excluded as follows: (I) 40 persons were aged 65 years or older and were able to walk independently and had a diagnosis of dementia made by a family physician with a score of 20 or less on the HDS-R; (II) 15 had a daily living independence level III or higher; (III) 5 had a history of cerebrovascular disorder; (IV) 5 had dementia with Lewy bodies; (V) 5 had dementia with frontotemporal dementia; (VI) 2 had frontotemporal dementia; (VII) 6 had a history of depression; and (VIII) 8 had difficulty communicating. The average age of the included 16 participants was 84.5 ± 3.9 years, and the sex ratio was 1:7. The median values for the cognitive, motivational, and emotional functions of MENFIS were calculated and classified into two groups. The median score for the MENFIS cognitive function was 20, and those with a score less than 20 were classified as the "high cognitive function group", while those with a score of 20 or more were classified as the "low cognitive function group". Next, the median score of the MENFIS motivational function was 8, and scores less than 8 were classified as the "high motivation function group" while scores more than 8 were classified as the "low motivational function group." Finally, the median score of the MENFIS emotional function was 6, and scores less than 6 were classified as the "high emotional function group" while scores more than 6 were classified as the "low emotional function group." The data obtained for the high and low cognitive function groups, high and low motivational function groups, and high and low emotional function groups were subjected to network analysis using graph theory to visualize their behavioral patterns. The betweenness centrality and clustering coefficients for each group are shown in Table 1.

The betweenness centrality of the high cognitive function group was as follows: Beacon 1 (B1) = 2.650, B2 = 0.650, B3 = 0.000, B4 = 2.650, B5 = 0.000, B6 = 1.000, B7 = 0.200, B8 = 0.200, and B9 = 0.650, and the clustering coefficient was 0.868. The betweenness centrality of the low cognitive function group was as follows: B1 = 1.500, B2 = 0.000, B3 = 0.000, B4 = 10.000, B5 = 0.000, B6 = 1.500, B7 = 0.000, B8 = 0.000, and B9 = 6.000, and the clustering coefficient was 0.521.

The betweenness centrality of the high motivational function group was as follows: B1 = 3.600, B2 = 0.400, B3 = 0.600, B4 = 0.600, B5 = 0.000, B6 = 0.000, B7 = 7.200, B8 = 0.200, and B9 = 0.000, and the clustering coefficient was 0.722. The betweenness centrality of the low motivational function group was as follows: B1 = 0.000, B2 = 0.000, B3 = 6.000, B4 = 0.000, B5 = 0.000, B6 = 0.000, B7 = 0.000, B8 = 0.000, and B9 = 0.000, and the clustering coefficient was 0.000.

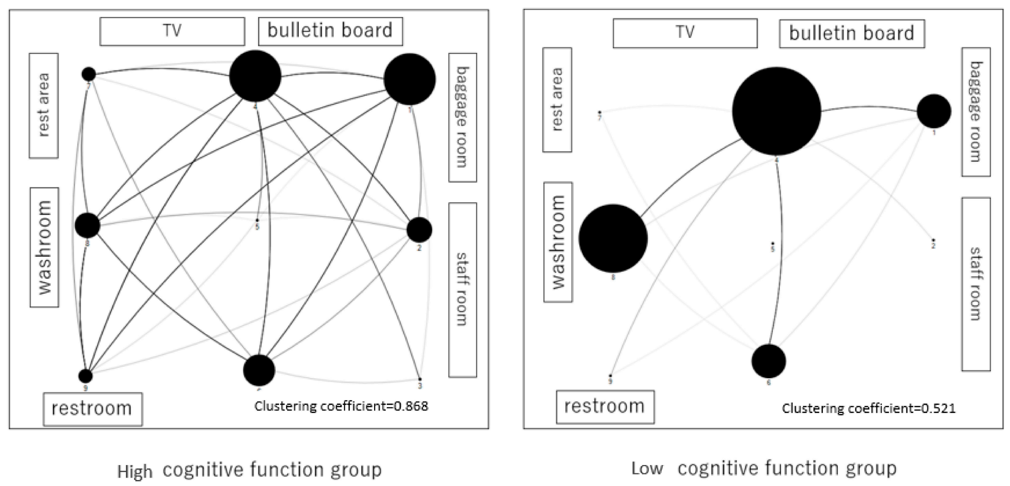
The betweenness centrality of the high emotional functioning group was as follows: B1 = 1.333, B2 = 0.000, B3 = 1.333, B4 = 1.333, B5 = 0.000, B6 = 0.000, B7 = 0.000, B8 = 0.000, and B9 = 0.000, and the clustering coefficient was 0.886.

The betweenness centrality of the low emotional functioning group was as follows: Beacon 1 (hereafter B) = 0.000, B2 = 0.000, B3 = 15.000, B4 = 1.500, B5 = 0.500, B6 = 0.000, B7 = 0.000, B8 = 0.000, and B9 = 0.000, and the clustering coefficient was 0.545.

The behavioral patterns of the high and low cognitive function groups, motivational function groups, and emotional function groups have been visualized, and the results of network analysis using graph theory are shown in Figures 1–3. The characteristics of the behavioral patterns of the high cognitive function group included high betweenness centrality of the TV stand/bulletin boards (B4 area) and luggage storage area (B1 area), and relatively high betweenness centrality of the staff waiting area (B2 area), hand washing area (B8 area), and toilet (B9 area). The edges which were relatively thick were spread out in each area in a well-balanced manner, indicating that the number of movements between beacons was also high. These behavioral patterns were interpreted as "moving to where they want to go of their own volition". In contrast, in the group with low cognitive function, the areas with high betweenness centrality were TV stand/bulletin boards (B4 area), luggage storage (B1 area), and hand-washing area (B8 area), and the number of movements in terms of edges was almost the same except for the areas with high betweenness centrality. These behavioral patterns were interpreted as "uniform behavioral patterns".

Next, in the group with high motivational function, the betweenness centrality of the rest area (B7 area), TV stand/bulletin board (B4 area), and luggage storage area (B1 area) were high, and the betweenness centrality of the staff waiting area (B2 area), hand washing area (B8 area), and toilet (B9 area) were also relatively high. The mediation centers in the staff waiting area (B2 area), hand washing area (B8 area), and toilet area (B9 area) were relatively high, and the edges indicating the number of movements were also spread out in many directions. These behavioral patterns can be interpreted as "moving to the necessary place at the necessary time." In the group with low motivational function, the only area with high betweenness centrality was the TV stand/bulletin board (B4 area), and there were few edges. These behavioral patterns are interpreted as "remaining stationary with almost no movement".

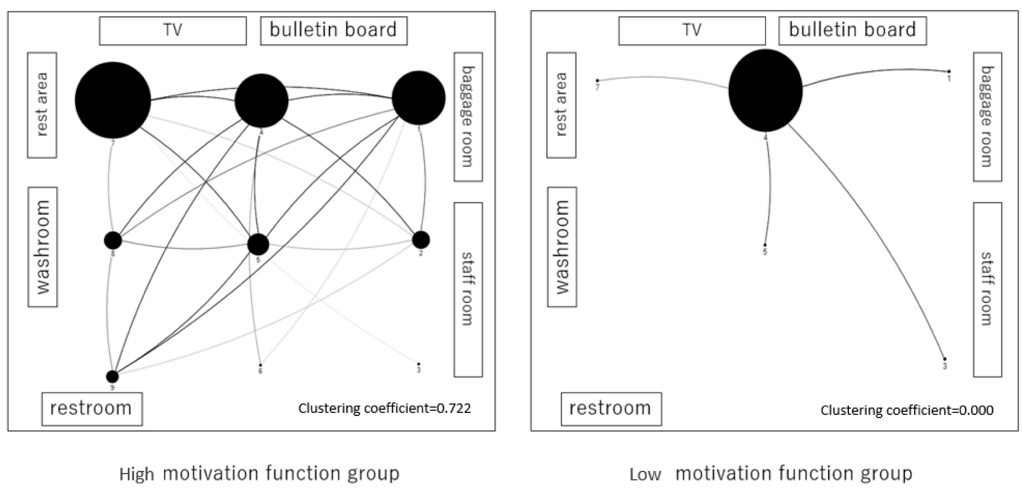
Finally, in the group with high emotional functioning, the betweenness centrality of the TV stand/bulletin board (area B4), luggage storage (area B1), and the center of the room (area B5) was high, the edges indicating the number of movements spread in multiple directions and the thickness of the edges suggested that the number of movements was also high. These behavioral patterns can be interpreted as "moving to the necessary place at the necessary time." In contrast, in the group with low motivational function, the only areas with high betweenness centrality were the TV stand/bulletin board (B4 area) and the center of the room (B5 area), and there were few edges, implying that the participants in this group did not move much. These behavioral patterns were interpreted as "staying in a fixed place."



High cognitive function group:
The TV stand and bulletin board (area B4) and the luggage storage area (area B1) had high mediating centrality, and the staffwaiting area (area B2), hand washing area (area B8) and toilet (area B9) also had relatively high mediating centrality. The edges are spread out in awell-balanced manner in each area, and the edges are relatively thick, resulting in a high frequency of movement between edges. It is interpreted tha they move to where they want to go when they want to go.

Low Cognitive function group:
The three areas with high mediating centrality were TV stand and bulletin board (area B4), luggage storage (area B1), and hand washing area (area B8), and the number of movement from the edge was also interpreted as almost no movement except to areas with high mediatingcentrality, i.e., the behavior was uniform.

Figure 1. Behavioral patterns of good and poor cognitive function groups visualized.



High motivational function group:
The mediating centrality of the rest area (area B7), TV stand/bulletin board (area B4), and luggage storage (area B1) is high, and the mediating centrality of the staff waiting area (area B2), hand washing area (area B8), and toilet (area B9) is relatively high. The edges indicating the number of moves are also spread out in multiple directions, and the thickness of the edges indicates that the number of moves is also high. It is interpreted that they are moving to where they need to be when they need to be there

Low motivational function group:
The only area with high mediating centrality was the TV stand and bulletin board (area B4), and there were almost no edges, which was interpreted as a behavioral pattern of staying in one place with almost no movement.

Figure 2. Behavioral patterns of good and poor motivational function groups visualized.

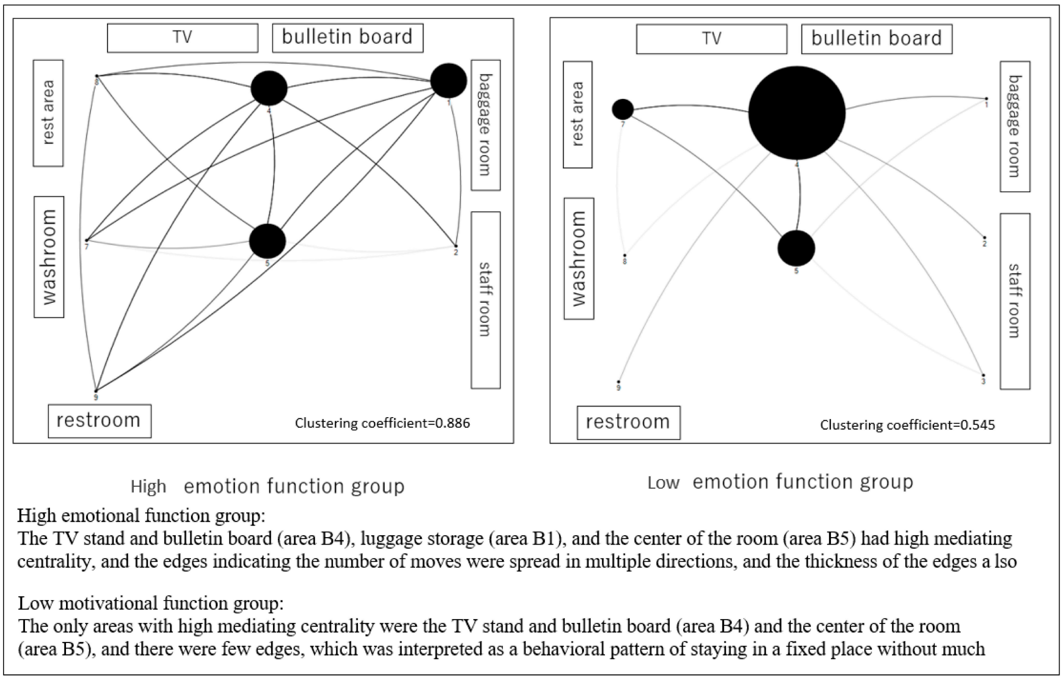


Figure 3. Behavioral patterns of good and poor motivational function groups visualized.

Table 1. Medio centricity and clustering coefficients for each group.

Groups	B1	B2	B3	B4	B5	B6	B7	B8	B9	Clustering coefficient
Good cognitive function group	2.650	0.650	0.000	2.650	0.000	1.000	0.200	0.200	0.650	0.868
Poor cognitive function group	1.500	0.000	0.000	10.000	0.000	1.500	0.000	0.000	6.000	0.521
Good motivation function group	3.600	0.400	3.600	0.600	0.000	7.200	0.400	0.200	0.000	0.722
Poor motivation function group	0.000	0.000	6.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Good emotion function group	1.333	0.000	1.333	1.333	0.000	0.000	0.000	0.000	0.000	0.886
Poor emotion function group	0.000	0.000	15.000	1.500	0.500	0.000	0.000	0.000	0.000	0.545

B = BEACON NUMBER.

DISCUSSION

Executive function refers to functions that play a role in cognitive processes. Cognition is defined as the process by which an organism actively collects information from the external world, perceives and stores it, and processes it by adding reasoning and judgment to obtain knowledge of the target [11]. Executive functions refer to higher-level cognitive functions that are involved in monitoring lower-level cognitive functions and behaviors [12]. Briefly, executive function can be described as a goal-directed cognitive function that is necessary to complete an action consisting of multiple steps from start to finish. This process requires the individual to set goals, plan actions, perform them in the correct order, manage deviations from the goals, and respond flexibly by modifying actions according to the situation. These functions are necessary for people to take action.

In the present study, the participants were generally patients with AD. Symptoms of AD include executive dysfunction, which appears early in the course of dementia, along with memory impairment [13]. These have already been shown in several previous studies [14,15]. In this study, the participants were categorized into high and low cognition groups based on the median cognitive impairment on the MENFIS; the behavioral patterns suspected of memory impairment in each group were then visualized and analyzed. The results indicated that the high cognitive function group showed a variety of behaviors, while the low cognitive function group showed uniform behaviors, implying impaired executive function in the low cognitive function group. This suggests that individuals with executive function deficits have uniform behavior patterns, are not able to set behavioral goals, plan their actions, perform them in the correct order, manage deviations from their goals, and are unable to flexibly modify their actions according to the situation.

In the present study, the motivational and emotional function scores of the MENFIS were also used to classify patients into high and low mental function groups, and the behavioral patterns of the two groups were analyzed. The behavioral patterns of the group with low motivational and emotional functions tended to be less mobile and stayed in the same place, and they showed little diversity [16]. Depression is the most well-known disorder of low motivation and emotional disturbance. Previous studies have shown that motivational and emotional disorders in depression decrease physical activity and narrow the scope of life and behavior. It is undeniable that motivational and emotional disorders affect the diversity of behavior in elderly people with dementia. In the present study, the behavioral patterns of the group with low motivational and emotional functions tended to be less mobile, tended to stay in the same place, and showed little diversity. In other words, impairments in motivation and emotional functioning have influence on the occurrence and diversity of behaviors [17,18]. As mentioned earlier, “behavior” in behavior analysis refers to behavior with behavioral concomitant, in which the frequency of occurrence of the subsequent behavior changes with changes in the environment. In the present analysis, we interpreted the “behavior” of the “now” of those with decreased motivation and emotional function as a state in which the behavior itself does not occur. On the other hand, it can also be interpreted as the “behavior” of standing still and not moving. In other words, the subsequent stimuli may be transformed by analyzing the preceding stimuli to understand why this “action” of “now” is occurring. To confirm these results, it is necessary to formulate hypotheses based on the present findings and to verify them empirically, which is a limitation of the present study and a subject for future developmental research.

LIMITATIONS

Since only 16 participants are included in this study, the study population cannot be considered to be reflective of the behavioral patterns of cluster representatives. Thus, increasing the number of participants and analyzing the behavioral patterns should be looked at in future studies.

CONCLUSIONS

In conclusion, the behavioral patterns of the high- and low-value groups for each of the three MENFIS sub-items, cognitive function, motivational function, and emotional function, were visualized, and the "behavior" of "now" was analyzed. The results suggested that the behavior of those with low cognitive function showed a uniform, stationary behavioral pattern, and the behavior of those with low motivational and emotional function were considered to be in a state where the behavior itself did not occur.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

DK and KY were responsible for the design and direction of the study. HB, AI, KK were responsible for data collection. DK and HB were responsible for the analysis and interpretation of the data. Drafting of the manuscript was done by DK, HB, AI, KK and KY were responsible for critical revision of the article for important content. All co-authors revised the final version and approved it for publication.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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