Psychological and Neurophysiological Effects of Robot Assisted Activity in Elderly People With Cognitive Decline

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Abstract

Robot-assisted activity (RAA) is a non-pharmacological therapy used to treat behavioral and psychological symptoms of dementia. This study investigated the immediate effects of RAA on psychological and neurophysiological indices. Twenty-eight elderly people were assigned to the cognitive decline group ($n = 11$) or control group ($n = 17$) based on their Mini-Mental State Examination scores. After 5-min RAA sessions that involved patients interacting with a communication robot, patient emotions and mood states were measured, and resting-state EEG activity and salivary cortisol were assessed before and after RAA. We found that compared with those in the control group, participants in the cognitive decline group did not enjoy RAA using the communication robot. This was corroborated by EEG findings indicating decreased relaxation immediately after RAA exposure. These results suggested that participants with cognitive decline had difficulty understanding the contents of communication with the robot. Our results indicated that elderly people who have cognitive decline and use day-service centers are less likely to experience the immediate benefits of RAA, including positive emotions and mental relaxation. To conduct effective RAA for such populations, it may be useful to select a method that is better understood and enjoyed by participants.

Keywords

cognitive decline, communication robot, elderly patient, electroencephalogram, robot assisted activity

Introduction

Worldwide, the number of elderly people with cognitive decline has been increasing due to rapidly aging populations (Prince et al., 2015) The behavioral and psychological symptoms of dementia (BPSD), which include agitation, aberrant motor behavior, anxiety, elation, irritability, depression, apathy, disinhibition, delusions, hallucinations, sleep, and appetite changes, introduce challenges to the care of such individuals. For one, it is difficult for people with BPSD to live at home on account on these symptoms (Kales et al., 2005; Okura et al., 2011), and BPSD has also been strongly associated with an increased sense of caregiver burden (Hiyoshi-Taniguchi et al., 2018). Therefore, palliative management of BPSD is considered an important factor that enables elderly people with such symptoms to continue to live at home and can reduce pressure on caregivers.

There are two types of treatment for BPSD: pharmacological (Dyer et al., 2018) and non-pharmacological (de Oliveira et al., 2015). While both types have been reported to reduce challenging behavior, non-pharmacological therapies have been the first choice for BPSD as they have fewer side effects. Various methods of non-pharmacological therapy have therefore been devised and applied in recent years, including robot-assisted activity (RAA). RAA sessions may help older adults with dementia feel less upset and lonely and gain more comfort by using the robot act as a catalyst (Abbott et al., 2019). A recent systematic review (Leng et al., 2019) showed a statistically significant decrease in BPSD, especially agitation and depression, in people

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with dementia treated with RAA using a pet robot. In addition, one study (Moyle et al., 2018) reported that a 10-week RAA intervention reduced overactivity in patients with dementia.

RAA is a countermeasure for mental health problems among the elderly (Shibata & Wada, 2011), proposed and developed by Shibata et al. (1996) for the purpose of providing pleasure and relaxation through interaction with robots (Wada et al., 2005). RAA has evolved from animal-assisted therapy, since robots have the advantage of avoiding the risks of animal allergies, infections, bites, and wounds (Shibata et al., 1996). The robots used in RAA include three alternatives: a pet type that provides emotional attachment by moving and crying (Petersen et al., 2017); a recreational type that performs gymnastics and quizzes (Kim et al., 2015); and a communication type that communicates with the target person (Valenti Soler et al., 2015). BPSD in elderly people with cognitive decline is thought to be caused by social isolation (Cohen-Mansfield & Werner, 1997) and the desire for social contact (Cohen-Mansfield & Mintzer, 2005). Furthermore, BPSD is reportedly reduced by social interactions (Cohen-Mansfield & Werner, 1997). Therefore, there is increasing interest in the communication robots used in RAA as a tool for alleviating BPSD.

The inhibitory effects of RAA on BPSD are mainly measured using neuropsychological indices (Jones et al., 2018; Moyle et al., 2017; Valenti Soler et al., 2015). This is insufficient as neurophysiological factors also play a role in disorder manifestation, given that cognitive decline emerges from both functional and organic changes in the brain. The neurophysiological effects associated with BPSD remain unclear (Kim et al., 2015; Petersen et al., 2017). Therefore, this study aimed to clarify the immediate neurophysiological changes caused by RAA in order to explore the neurophysiological factors underlying the effects of RAA on BPSD reduction.

Herein, we conducted RAA using a communication robot for a group of elderly people with cognitive decline (cognitive decline group) and a control group of elderly people with normal cognitive function. We examined the changes in psychological and neurophysiological factors before and after the intervention, with the aim of clarifying its immediate psychological and neurophysiological effects. We hypothesized that RAA intervention would produce neuropsychological and neurophysiological positive effects regardless of the subject's cognitive functioning.

Materials and Methods

Participants

This study was conducted with 28 elderly people (11 males, 17 females; mean age: 79.4 ± 7.0 years; mean height: 154.5 ± 10.4 cm; mean weight: 54.5 ± 12.5 kg) with no orthopedic or nervous system disease, including motor deficits and sensory disorders. Two day-service

centers in Japan were used as measurement facilities, and the facilities' staff recruited participants among users of day-service centers. Written informed consent was obtained from these individuals prior to participation in accordance with the Declaration of Helsinki. The participants' general cognitive function was measured prior to the intervention using the Mini-Mental State Examination (MMSE) (Folstein et al., 1975). Based on their MMSE scores, the participants were divided into the cognitive decline group (MMSE score < 24) and the control group (MMSE score ≥ 24), following a cut-off threshold widely used to detect cognitive decline (Sugishita et al., 2016).

Study Intervention

For the intervention, participants individually received a 5-min RAA session while sitting on a chair with a backrest. The RAA was performed using Chapit, a communication robot that has the appearance of a stuffed toy and is equipped with a speech recognition system (RayTron Inc, Osaka, Japan). Chapit would recognize a predetermined phrase and respond using a voice reproduction software that mimicked a 5-year-old boy. Additionally, Chapit can perform recreational activities such as prefecture quizzes (regional or culturally based quizzes in Japan), arithmetic games, memory games, and singing.

Participants were given Chapit and a paper containing a list of phrases (e.g., "good morning," "What time is it?" "Please say something interesting," etc.). The researcher then presented a short introductory script:

> "This is Chapit. Chapit is a communication robot. Chapit will respond when you talk to Chapit. Let's talk with Chapit using words from the phrase list."

Outcome Measures

All measurements, including those for emotion and mood states, resting-state EEG, and salivary cortisol levels, were conducted by the designated researcher. Emotions and mood states were assessed after the RAA session (Goda et al., 2020). A 5-point scale developed with reference to the Likert scale (Likert, 1932) (1 = strongly disagree to 5 = strongly agree; higher scores indicated positive emotions and mood states) was used to measure the degree to which participants felt warmth, enjoyment, and a sense of task accomplishment (i.e., spoke well with robot).

EEG measurements are an indicator reflecting subjects' emotional changes with high temporal resolution (Al-Qazzaz et al., 2019). Resting-state EEG activity was measured for 120 s in the eyes open condition, both before and after the RAA session while participants were seated in a chair with a backrest. The EEG was obtained using the electroencephalograph Discovery 24E (BrainMaster Technologies Inc., Bedford, Massachusetts, USA) and an active dry electrode system (Miyuki Giken Co. Ltd., Tokyo, Japan). The EEG

Table 1. Demographic Characteristics of People in the Cognitive Decline Group and the Control Group.

Variable	Cognitive decline group (n = 11)[*]	Control group (n = 17)[*]	p-value
Sex (male/female; n)	7/4	4/13	.08[a]
Age (year)	79.00 (5.46)	79.59 (8.05)	.83
BMI	21.30 (3.66)	23.68 (3.54)	.13
MMSE (Score)	17.82 (3.79)	27.29 (2.34)	<.01[b]

Note. n = number; BMI = body mass index MMSE = Mini-Mental State Examination.
[a]χ^2 test.
[b]U-test using independent samples.
[*]All values (except sex) are presented as means (standard deviations). Cognitive decline group: MMSE score < 24; Control group: MMSE score = 24. t- test using independent samples.

Table 2. Comparison of Emotions and Mood States After Robot Assisted Activity.

Variable	Cognitive decline group[*]	Control group[*]	p-value
Warm (scores)	3 (3–5)	4 (3–5)	.38
Enjoyment (scores)	3 (2–4)	5 (2–5)	<.01
A sense of task accomplishment (scores)	3 (2–5)	3 (1–5)	.30

[*]All values are presented as medians (minimum–maximum). Cognitive decline group: MMSE score <24; Control group: MMSE score ≥24. Fisher's Exact test using independent samples.

was recorded with two channels [Fz (frontal midline region) and Pz (parietal midline region)] based on the international 10–20 system and at a sampling rate of 256 Hz. Reference electrodes were attached to both earlobes.

Recorded EEG data were processed using the commercial software Brain Vision Analyzer 2.0 (Brain Products, Munich, Germany). First, the band pass filter was set to 1 to 40 Hz and segmented into 2-s epochs. Next, fast Fourier transformation (FFT) was used to calculate the EEG power for each epoch. The alpha (9–13 Hz) and beta (13–20 Hz) power, obtained from the FFT spectra, was averaged over trials for each participant, electrodes (Fz, Pz), and measurement period (pre- and post-session). The participant's emotional response was calculated as the relative power index (alpha/beta) (Dehghanpour & Einalou, 2017). We predicted that the RAA intervention would produce an increase in alpha/beta at Pz, indicating a state of mental relaxation in the participants.

Salivary cortisol was measured from resting saliva samples taken before and after the RAA session. The saliva sample was collected using a SOMA oral fluid collector (OFC) (SOMA Bioscience, Wallingford, UK). Participants themselves placed one OFC swab on top of their tongue and closed their mouth. When 0.5 ml of saliva had been absorbed by the OFC, an indicator line on the swab stem turned bright blue at which point the OFC was removed from the participant's mouth and placed in a 3-ml buffer solution. The SOMA Lateral Flow Device (LFD; SOMA Bioscience, Wallingford, UK) and the SOMA Cube Reader (SOMA Bioscience, Wallingford, UK) were used to analyze saliva samples. We predicted that the RAA intervention would result in a reduction in salivary cortisol, which is indicative of the participants' mental relaxation.

Statistical Analyses

The baseline characteristics of the cognitive decline group and control group were compared to check if the two groups were comparable. The Shapiro–Wilk Test was used to test the normality of the distributions. Differences between groups were analyzed using the Student's t-test for normally distributed variables and the Mann–Whitney U test for variables that were not normally distributed. Data regarding emotions and mood were not normally distributed, so we compared them using the Fisher's Exact test. A two-way analysis of variance (ANOVA) with Bonferroni post hoc analysis was used to assess any differences between the groups ("group"), time intervals ("time"), or their interaction (group × time) in the resting-state EEG activity and salivary cortisol values. Statistical analyses were performed using SPSS 24 (IBM, Chicago, Illinois, USA) and R 3.5.3 (R Foundation, Vienna, Austria). The level of significance was set at $p < .05$.

Results

All participants attended RAA sessions and completed each 5-min session. Before the RAA, there were no significant differences between the two groups in terms of participants' gender percentage, age, and BMI (all ps > .05; Table 1)—except for the MMSE scores ($p < .01$). The degree to which participants felt "enjoyment" following the RAA was significantly higher in the control group than in the cognitive decline group ($p < .05$; Table 2). There were no significant differences observed in terms of "warm" and "a sense of task accomplishment" between the two groups (both ps > .05; Table 2).

The effects of RAA on the alpha power, beta power, and relative power index (alpha/beta) on both Fz and Pz are presented in Table 3. A significant main effect of the

Table 3. Means and Standard Deviations of the Three Main EEG Indices for each Participant Group and Measurement Period in the Fz and Pz Regions.

Variable		Cognitive decline group*		Control group*		*p*-value		
		Pre-RAA	Post-RAA	Pre-RAA	Post-RAA	Group	Time	Interaction
Fz	α (μV)	57.97 (20.88)	44.78 (31.21)	57.59 (26.81)	48.80 (15.52)	.78	.10	.74
	β (μV)	105.27 (44.80)	109.29 (42.01)	125.81 (86.21)	105.38 (24.80)	.59	.60	.43
	α/β	0.59 (0.19)	0.41 (0.19)	0.49 (0.13)	0.48 (0.15)	.66	.04	.06
Pz	α (μV)	48.48 (10.05)	35.00 (11.90)	55.40 (21.34)	52.78 (30.09)	.04	.18	.36
	β (μV)	89.27 (27.40)	91.43 (16.97)	110.89 (50.79)	102.72 (50.32)	.16	.80	.66
	α/β	0.57 (0.16)	0.40†‡ (0.15)	0.52 (0.12)	0.53 (0.20)	.32	.07	.04

Note. EEG = electroencephalogram; Fz = frontal midline region; Pz = parietal midline region; RAA = Robot assisted activity; α = alpha (9–13 Hz) frequency band power; β = beta (13–20 Hz) frequency band power; α/β = relative power index calculated by alpha frequency band power/beta frequency band power.
*Values are presented as means (standard deviations). Cognitive decline group: MMSE score <24; Control group: MMSE score ≥24. Two-way ANOVA with Bonferroni post hoc analysis was performed for statistical analysis.
†Cognitive decline group-pre versus cognitive decline group-post; $p < .05$.
‡Cognitive decline group-post versus control group-post; $p < .05$.

Table 4. Means and Standard Deviations of Salivary Cortisol for each Participant Group and Measurement Period.

Variable	Cognitive decline group*		Control group*		*p*-value		
	Pre-RAA	Post-RAA	Pre-RAA	Post-RAA	Group	Time	Interaction
Salivary cortisol (nM)	7.93 (6.62)	4.22 (3.06)	4.39 (2.82)	3.43 (2.16)	.04	.08	.19

Note. RAA = Robot assisted activity; nM = nanomolar.
*Values are presented as means (standard deviations). Cognitive decline group: MMSE score <24; Control group: MMSE score ≥24. Two-way ANOVA with Bonferroni post hoc analysis was performed for statistical analysis.

"time" factor was found for the relative power index (alpha/beta) on Fz ($F = 3.72$, $p < .05$), indicating a decrease in relative power index (alpha/beta) after RAA. Furthermore, a significant main effect of the "group" factor was found for alpha power on Pz ($F = 4.38$, $p < .05$), showing a lower alpha power on Pz in the cognitive decline group than in the control group. Additionally, a significant "interaction" effect was found for the relative power index (alpha/beta) on Pz ($F = 4.65$, $p < .05$), meaning that differences in group attributes influenced relative power index (alpha/beta) changes on Pz by RAA. As a result of the Bonferroni post hoc analysis, the relative power index (alpha/beta) on Pz significantly decreased after RAA in the cognitive decline group (Pre-RAA 0.57 ± 0.16 vs. Post-RAA 0.40 ± 0.15; $p < .05$), and the relative power index (alpha/beta) on Pz after RAA was significantly lower in the cognitive decline group (cognitive decline group Post-RAA 0.40 ± 0.15 vs. Control group Post-RAA 0.53 ± 0.20; $p < .05$).

The effects of RAA on salivary cortisol values are presented in Table 4. A significant main effect of the "group" factor was found ($F = 5.16$, $p < .05$), indicating that salivary cortisol values were higher in the cognitive decline group than in the control group.

Discussion

In this study, the immediate effects of RAA using a communication robot on elderly people with cognitive decline were examined using the following parameters: emotional and mood states immediately following RAA; resting state brain activity and salivary cortisol before and after RAA. These parameters were compared between a group of elderly people with cognitive decline and a those with normal cognitive function. The results of this study suggested that it is difficult for elderly people with cognitive decline to achieve immediate positive emotional and mental relaxation effects from RAA using a communication robot.

The entire sample provided similar (neutral) ratings for the warmth of the communication robot and their sense of task accomplishment following RAA, regardless of their cognitive function. However, there was a significant difference in their reported experience of "enjoyment" such that the cognitive decline group reported neutral scores, while the control group reported significantly higher (positive) scores. A previous study (Goda et al., 2020) of 12 elderly women with normal cognitive function (MMSE 27.7 ± 2.2 points) reported a median Fun score of 5, a trend similar to that of the control group in this study. It should be noted that people with Alzheimer's disease—the major dementia disease—can have language impairment that results from a decline in semantic and pragmatic levels of language processing (Savundranayagam et al., 2005). Thus, it is possible that the participants in the cognitive decline group could not appreciably understand the conversation with the robot, which could have led to reduced enjoyment relative to the control group.

Moreover, we observed a significant decrease in the relative power index (alpha/beta) on Fz after RAA in both groups. This reflects an increase in relative beta power, suggesting activation of the brain region. These results should be interpreted with caution due to the potential issue of reverse inference when interpreting brain wave data that is superimposed onto the brain region (Poldrack, 2011). However, we considered the neural activity of the Fz channel to correspond with the activity of the supplementary motor area (SMA) based on the interpretive methodology used in previous studies (Weersink et al., 2019). Moreover, an increase in SMA activity has been reported during verbal mental-operation tasks (Tanaka et al., 2005). In this study, the verbal mental-operation during the conversation with the communication robot was thought to be performed in the following series of processes: listening to the response from the robot, recognizing the relationship with the phrase that the user spoke, and understanding the intention. As a result, the activity in the SMA of the participants increased, and the relative power index (alpha/beta) on Fz decreased.

The alpha power on Pz was lower in the cognitive decline group than in the control group. The increase in alpha power in the posterior parietal region, which is reflected by Pz, is a physiological index indicating a state of mental relaxation (Jensen et al., 2007). It has been shown that people with cognitive decline have been feeling mental stress for a long time due to lack of understanding or misunderstanding from those that surround them (Sharp, 2019). This would explain why the alpha power of Pz was low in the cognitive decline group.

Furthermore, an interaction effect was observed in relative power index (alpha/beta) on Pz, suggesting that the effect of RAA differs depending on the group. The post hoc analysis showed that, in the cognitive decline group, the relative power index (alpha/beta) on Pz decreased significantly after RAA, and the relative power index (alpha/beta) on Pz after RAA was significantly lower than that in the control group. This decrease indicates a decrease in the relative alpha power, suggesting that the relaxed state was reduced (stress was increased) after RAA in the cognitive decline group. A previous study had reported a lack of communication skills in people with dementia (Machiels et al., 2017). Therefore, participants in the cognitive decline group may have had difficulty communicating with the communication robot and thus felt mental stress.

Finally, the salivary cortisol levels were significantly higher in the cognitive decline group than in the control group. As previously mentioned, people with cognitive decline are prone to chronic mental stress (Sharp, 2019), and increases in salivary cortisol levels due to chronic mental stress in people with cognitive decline have been previously observed (Souza-Talarico et al., 2009). This is a probable explanation of the higher levels of salivary cortisol in the cognitive decline group. On the other hand, there were no group differences in changes in salivary cortisol due to RAA, despite the fact that the EEG indices suggested differences in stress between the groups. The peak change in cortisol levels after stress has been reported to occur 20 min after task completion (Khalfa et al., 2003). In the present study, salivary cortisol was measured immediately after the intervention, which may have failed to capture the maximum change in salivary cortisol concentration produced by the RAA intervention.

The present study does have some limitations. First, the sample size of this study was small, warranting corresponding cautious interpretation. To corroborate the findings of the present study, a subsequent study with a larger sample size of approximately 130 people [priori test by G*power (two-way ANOVA); effect size f: 0.25; α error prob: 0.05; Power ($1-\beta$ error prob): 0.8; Numerator df: 1; Number of groups: 4] is needed. Second, this study was conducted with elderly people using a day-service center, and therefore, the results of this study may be relevant only in this population. In order to further generalize these findings, it is necessary to investigate them in other populations. Third, it is possible that an immediate effect was not recognized in participants with cognitive decline because the communication content of the robot was too difficult. In the future, it will be useful and even necessary to conduct research using robots whose conversation contents have been modified to be more easily understood. Fourth, the two-channel EEG measurement method used in this study meant that state-of-the-art brain wave data processing to control for artifacts could not be performed. Future studies could aim to obtain multi-channel measurements and perform appropriate artifact processing on the EEG data. Fifth, salivary cortisol was measured immediately after the intervention, which may not have captured the peak of salivary cortisol changes caused by RAA. Future studies should examine changes in salivary cortisol over time after the intervention. Sixth, judgment of cognitive decline based on MMSE scores alone is not sufficient. Additional and extensive cognitive function test for participants would be useful. Finally, the long-term effects of RAA using a communication robot and its effects on individuals with cognitive decline have not been studied. People with cognitive decline are often more comfortable with familiar objects and places rather with novel situations. Therefore, long-term RAA intervention may alter the participant's response to RAA as they become accustomed to it. Future studies are needed to verify the long-term effects of RAA. Given these points, the results of the present study should be considered as preliminary, and further studies addressing the above-mentioned limitations are necessary.

Conclusion

This study investigated the immediate effects of RAA using a communication robot on psychological factors,

EEG activity, and salivary cortisol in elderly people with cognitive decline relative to those with normal cognitive function. Our results demonstrated that elderly people with cognitive decline have higher levels of mental stress and are, therefore, less likely to experience the immediate benefits of RAA, such as positive emotions and mental relaxation. We concluded that to conduct effective RAA for elderly people with cognitive decline, it may be useful to select a more conducive method that is better understood and enjoyed by such patients.

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Author Contributions

AG: conceptualization; formal analysis; investigation; original draft preparation. TS: conceptualization; supervision. SM: methodology; review and editing. TK: methodology; data curation; review and editing. HN: data curation; review and editing. HO: resources; review and editing.

Declaration of Conflicting Interests

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Ethical Approval Information

This study was approved by the Ethics Committee at Kyoto Tachibana University (Approval number: 18-56).

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