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Can connected technologies improve sleep quality and safety of older adults and care-givers? An evaluation study of sleep monitors and communicative robots at a residential care home in Japan

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ABSTRACT

A sheet-shaped body vibrometer (SBV) is a type of assistive technology which offers a constant and noninvasive method of recording and monitoring the physical condition and sleep patterns of care recipients. With the aim of creating a safer environment for both care recipients and caregivers, we connected the SBV to a communicative robot (com-robot), to function as an integrated system. The robot has a sensor which activates when a care recipient tries to stand up, whereupon it sends an alert to care staff and speaks to the care recipient. The combined technologies offer an enhanced sense of security, as they watch over older people during the night, visualise sleep patterns and alert care staff. As proof of concept, this study examines the usefulness of this connected system by testing its effectiveness among two types of users (care recipients and professionals) in a residential care home in Japan. For the former, sleep parameters were investigated to see if there was any change over time in and impact on an older person's quality of life. As a measurement of quality of life, the interRAI method was used as a comprehensive assessment tool, based on which a care plan was also created for each care recipient. The interRAI is a nursing care evaluation and nursing care plan creation guideline package that provides unbroken care that can be used at home, in facilities or in the community For the latter, the study tests the level of fatigue among care professionals during night shifts before and after the intervention. For triangulation of data, semi-structured interviews and usability tests were carried out. Despite a few points for improvement, the results highlight multiple benefits for care recipients and professionals of using the SBV and com-robot integrated system in a residential care home.

1. Introduction

All industrially advanced economies are facing the challenge of an ageing society, with people wishing to lead an independent and active life in their private environment and community for as long as possible. Many recent studies show promising signs of technological solutions that could support 'ageing in place' [1–3] by creating an ambient assisted living system with in-home monitoring. The ultimate goal of introducing assistive technologies should be empowerment, enablement and enhanced QOL of older persons, and proper evaluation including users' lived experience should be carried out [4–6].

At the same time, residential care facilities remain one major form of eldercare provision in many societies, including Japan, where the proportion of older people grows at a fast speed (27.7% as of 2018) and the size of the older population (approximately 35 million) is overwhelming in comparison to other countries [7]. Care facilities are in high demand, and their number and demand for them are on the increased. In Japan, there are different types of care facilities. One type is a special nursing home for older people (what is known in short as Tokuyō). Greater levels of care are typically needed by users in a special nursing home, and it is

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often a place where they stay for the rest of their life. There are 530,280 such facilities, as of 2016, while there are also 370,366 geriatric health service ('step-down') facilities, preparing residents for independent living at home, and 482,792 fee-charging residential homes for older adults [7]. Therefore, it is crucial to investigate whether and the way in which installed assistive technologies can contribute to building a safer care system in residential care homes.

In Japan, due to increasing demand, work pressure and an estimated shortage of carers, the integration of robots and ICT technology into care provision and daily life has been given serious thought in Japan. Robots and care-monitoring systems are already commercially available in the country, and a strong impetus exists for bringing these innovative assistive technologies into care facilities and private homes to alleviate some of the pressures.

A sleep monitor is a type of assistive technology, although by itself only provides assistance to caregivers by way of visualising sleep patterns of care recipients. In order to create a safer environment where both care recipients and caregivers can feel the difference, a sleep monitor was connected up with a communication robot. When combined with other devices, it can be defined as a robot in Japan according to the Japanese Ministry of Health, Labour and Welfare (MHLW). A robot is an intelligent mechanical system with three main functions (detecting, assessing, and acting on the information) [8,9]. Care robots are broadly classified into three types (Table 1).

By connecting up two devices, the robotics-aided sleep monitoring system fosters interactions and brings out the otherwise "invisible" care quality issues such as sleep patterns of care recipients and nighttime work shifts for caregivers. The robot has a sensor which activates when a care recipient tries to stand up, whereupon it sends an alert to a care staff member's mobile phone and speaks to care recipients, reassuring that staff are coming shortly.

Recent research focuses on the usability of ICT technologies, acceptance of these technologies by older persons [10,11], ethical issues surrounding the use of monitors [2] and evaluation of outcome measures such as Quality of Life (QOL) [12–14]. While empirical studies began to highlight the usefulness of these technologies [15–18], some relevant questions remain unanswered [19,20]. For example, when several technologies are bundled together, would that decrease usability as perceived by care staff? Also, is robotics-aided care welcomed by multiple users? How do we know whether using assistive technologies has improved the care system? While older people's QOL should be the primary goal, the impact on other users, particularly care professionals, should also be examined.

As a measurement of QOL, the interRAI method [21] is a comprehensive assessment tool for care recipients' QOL, and can also be used to create a care plan. The interRAI was derived from the Minimum Data Set–Resident Assessment Instrument (MDS-RAI) method that was widely used in Europe and the United States. It is a nursing care evaluation/nursing care plan creation guideline package that provides unbroken care that can be used at home, in facilities or in the community [22]. There have not been many studies using such a comprehensive and standardised tool, with a few exceptions [23].

Table 1
Three types of care robots.

Type	Primary target users	Examples
Physical support type	Caregivers	Power suits, a modular robot arm (e.g. RIBA) and robots that assist with bathing, dining, excretion and sleep (e.g. iCareRobot, Nemuri-scan) and transferring (e.g. Toyota Porte)
Independence support type	Care recipients living autonomously	Powered exoskeletons (e.g. HAL, WPAL), and mobile arm/hand support (e.g. MARo, RAPUD)
Communication, comfort and safety monitoring type	Care recipients being paired up with care givers	Safety monitoring (e.g. WAKAMARU), giving guidance to people with dementia (e.g. Sota), and companionship (e.g. Aibo, Paro, Qoobo).

Sources: AIST, 2017 [9].

On a broader level in the ICT domain, many studies have examined older people's acceptance of technology [11,24]. The important attitudinal factors explaining acceptance and usage are perceived usefulness, perceived ease of use, perceived risk, cost and self-efficacy [25–29]. The provision of introductory guidance and training for the users, particularly care professionals, is also highlighted [30,31]. In introducing ICT equipment in the nursing care area, it is important to have intermediaries, families and caregivers between equipment and older people. Considering that care professionals may not have ICT [24], the introduction of ICT equipment is generally difficult. However, it remains to be seen whether there is any association between the interest in care robots and that in technological devices. Such devices need to be evaluated also from the viewpoint of a carer's comfort, and acceptability by the carer.

As mentioned above, empowering carers is also one of the key deciding factors in facilitating the integration of care and assistive technologies. One fertile area can be found in the measurement of the sleep quality of care recipients and the resulting effects for care professionals. Falls are a very well-known problem in older adults [32], but it is a particularly acute and problematic issue in residential care homes. Excessive use of psychotropic drugs and antihypertensive agents is a promoting factor for delirium and night wandering, and then the risk of falls at night increases [16].

Approximately half of older people's falls take place in care facilities [33], and among hospitalised patients, about 80% of fall-related adverse events occurred during the night [34,35]. Securing better sleep quality at night is therefore a concern for all those involved in care settings. It is also well known that older people with dementia have more frequent sleep disorders than normal persons [36]. According to Rongve et al. [37], 71% of people with dementia have sleep disorders (insomnia, cramps in sleep, sleepiness during daytime, restless legs syndrome, REM sleep behavior disorder).

Compared with daily activities such as eating, toileting and physical transfer, sleep has been 'hidden' to care professionals, while watching over during the night is considered to be a basic and essential task of nursing care [38]. Therefore, if a robot not only provides the safety function of watching over, but also offers data to uncover what was previously 'hidden', such as the meaning and mechanism of sleep (e.g. high quality sleep, good state of sleep, timing of insomnia), it means empowerment for care professionals as well as care recipients. The monitoring of care recipients at night also results in the reduction of night-time nursing staff's physical and mental burden [15,39].

The sleep quality of older people living in a residential care home is characterised by an increase in total bed time, total sleep time, mid-sleep awake frequency, and the number of times leaving bed during sleep [40]. Insomnia is a causal factor for delirium, night-time wandering and frequent nocturia, which all increase the risk of fall and bone fracture [41]. Sleep disorder itself is a risk factor for dementia [42]. Sleep disorder lowers the QOL of the older people in nursing homes and then increases the care burden of professionals. An appropriate response to insomnia is an important aspect of medical care for older people. Fig. 1 shows a schematic diagram of the set-up for this research and anticipated benefits for care recipients and caregivers.

Against such a background, this study aims to examine the effectiveness and perceived usability of non-wear actigraphy devices, connected up with communicative robots, in a residential care facility. The device introduced (NemuriSCAN®, Paramount bed Co., Tokyo, Japan) was a sheet-shaped body vibrometer (hereafter SBV), which has a pressure sensor that reacts to pressure changes due to body movements on the mattress (Fig. 2). Nemuri means 'sleep' in Japanese, and therefore the product name *NemuriScan* means 'sleep scan'. The SBV provides

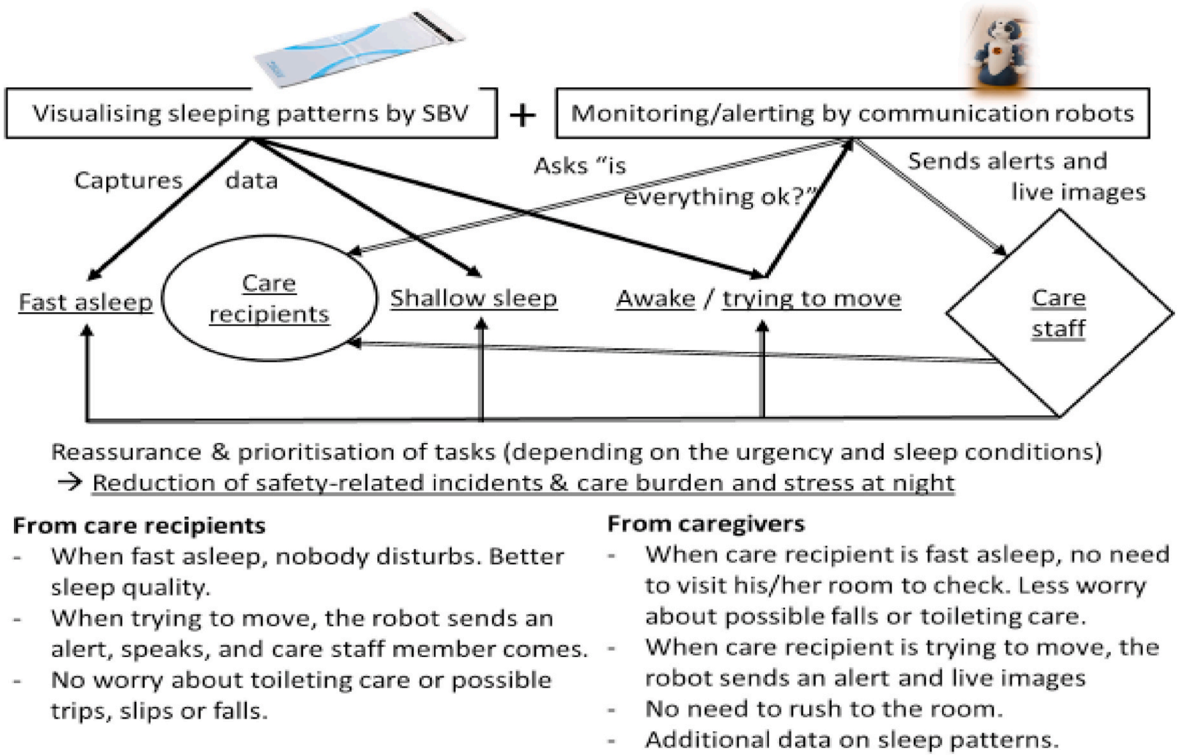

Fig. 1. Schematic diagram of the SBV + ComRobots Integrated System (SCIS) and its possible benefits for care recipients and caregivers.

noninvasive and continuous measurement of sleep/wakefulness with the same accuracy as polysomnography [43,44]. This particular SBV measures the heart rate and respiratory rate. This device was also used to measure sleep patterns in patients with Alzheimer's disease [45]. The specification of the product is (length) 284 mm × (width) 775 mm × (thickness) 18 mm, and its safe working load is 138 kg.

Although the device is classified as Type 1 (Table 1), the SBV, connected with a communication robot (hereafter SBV + ComRobot Integrated System, SCIS for short), straddles Types 1 and 3, as it also provides safety monitoring and interacts with care recipients via basic communications. The ComRobot is called Cota (Vstone Co. Ltd. Tokyo, Japan). The size is (height) 280 mm × (width) 140 mm × (depth) 160 mm. The robot has eight degrees of freedom, with a conversation engine (Linux) and CPU (Intel (R) Edison). The input/output devices are a camera, a monaural microphone, a speaker and lights (LED), and WiFi functions.

By looking at a more comprehensive package of potential benefits of the SCIS for both users (care recipients and care professionals), this study utilised a set of widely-used evaluation tools such as interRAI and the System Usability Scale (SUS).

Therefore, the main research question was whether connected technologies (an SBV combined with a communication robot) can contribute to a safer care system by improving the sleep quality of care recipients and reducing stress levels among caregivers in a residential nursing home. By connecting up different devices, particularly robots and alert systems on mobile phones, it was hypothesised that additional complexities might arise and potentially create negative responses from care staff. The objectives of this study were two-fold: first, to validate the

Fig. 2. Sleep monitor installed in bed.

usefulness of SBV as a monitoring instrument for care recipients and care professionals; and second, to evaluate the perceived usability and acceptability of the SCIS among care professionals working in a nursing care facility, based on their ICT literacy.

2. Methods

2.1. Study design

This was a 4-week pre/post introduction, proof-of-concept study, conducted between December 2017 and December 2018. The SBV was installed in a residential care facility and for the duration of 4 weeks, the evaluation was carried out before, during and after the period. To evaluate the impact and triangulate the data, semi-structured interviews were conducted at the end of the 4-week period.

For each participant, one SBV sensor-installed mat is placed under the mattress of the bed, around the position of the chest of the user, to monitor body movement, respiration movement, and heart beats. By measuring the frequency and intensity of body movement before 4 min and after 2 min, it makes it possible to determine the sleep/awakening state every minute. SBV works for a long time without any burden on the user. The ComRobots were also distributed to each participant, as Fig. 3 illustrates.

2.2. Participants and setting

Twenty five older adults living in a residential care facilities agreed to take part. The inclusion criteria for individual participants were whether they can express their will, and we received consent from their carers and family members.

The average age of the participants was 85.9 ± 9.0 years, with their average care degree being 3.1 ± 1.1. From the care professional group, 15 staff members (13 nurses and 2 care workers) in charge of looking after the residents participated. Out of these 15, twelve performed night-shifts.

In Japan, there are different types of care facilities. The facility selected for this study is a special nursing home for older people. There are 30 residents. The same organisation manages a 'step-down' facility with 70 beds. Approx. 100 staff members, including doctors, care professionals, care managers, nurses, nutritionists, and counselors work in the organisation.

In this facility, a number of initiatives have been taken to improve the work environment. In trying to realise person-centred care in the local community, Maslow's hierarchy of needs [46] has been used as an organisational vision. Therefore, the goal is not only to create a workplace to meet the basic and psychological needs of care professionals, but also to realise an environment where a sense of community, respect, recognition and self-actualisation can be achieved. It is widely recognised that a sense of purpose in life ('ikigai' in Japanese) is very important for active ageing in Japan. In a similar manner, at work, a sense of purpose and intangible rewards ('yarigai' in Japanese) have been openly discussed in this organisation. Proactive attitudes towards involvement in research activities (including this study) were guided by this theory of motivation and self-actualisation [46]. A range of other activities that have been introduced to make the facility rooted in the local community include: community radio programme, local festivals in conjunction with schools, and disaster prevention drills. With the community-oriented approach to enhance the quality of human care, the introduction of the SBV and the ComRobots was considered and the testing was conducted.

2.3. Data collection

2.3.1. Care recipients – sleep patterns

The sleep parameters are the most important factor for assessing the quality of older people's sleep. These parameters, presented as images and numerical data, were collected directly from SVB for 25 participants. The key figures here are the parameters themselves, changes over time, and how those changes are related to the quality of sleep.

2.3.2. Care professionals – fatigue level

For ten care professional participants, a fatigue degree questionnaire survey was carried out five times per day for each care professional during night shifts (before work at 16:30, pre-dinner at 20:00, pre-nap at 00:00, post-nap at 02:00, end of work at 09:50). Changes in the level of work stress and psychological state were collated during the test period

Fig. 3. Communication robot alerting system.

and compared. Twenty-five subjective fatigue items are included in this questionnaire, developed by the Industrial Fatigue Research Committee of Japanese Occupational Health [47]. These 25 items are finally categorised into five factors of feeling: drowsiness; instability; uneasiness; local pain or dullness; and eyestrain. These 'Subjective Symptoms' are regarded as a standard investigation method for measuring the degree of fatigue burden on workers and care professionals [48,49].

2.3.3. Care professionals – perceived usability

For testing the perceived 'ease of use' of the device, the data were collected using the SUS for 15 care professionals looking after those ten participants described above. The tool was originally developed in 1986 to measure users' satisfaction with VT100 - a video terminal produced by Digital Equipment Corporation. It has been validated and widely used [50]. It is a 10-item Likert-scale questionnaire (see Appendix A), and the items include respondents' perceived usability, complexity, and confidence with the device.

To complement this questionnaire, subsequently, semi-structured interviews were carried out with the 15 care professionals conducted in July 2018. The semi-structured interview survey contained questions concerning their perceptions of care, patient experience, teamwork, leadership and their perceived usefulness of the sleeping monitor. These qualitative data were collected to provide staff's feedback in more detail.

2.4. Statistical analysis

As this study was designed to evaluate the effects of introducing the two integrated technologies, the pre- and post-introduction data were collected, and the Wilcoxon code rank sum test was used. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan). $P < 0.05$ was considered statistically significant. In addition, the semi-structured interview data were analysed according to care staff's positive and negative attitudes towards the two devices.

Ethical approval

Ethics approval was granted by the Social Welfare Corporation Tokyo Sacramental Ethics Committee (TS 2017–002). Consent was sought from each participant and their family. The research was conducted between December 2017 and January 2018.

3. Results

3.1. Data from SBV – sleeping patterns of care recipients

The following two tables show the sleep analysis recorded by SBV.

Table 2
-a. Sleep parameters (mean ± SD) in Week 1 and 4.

	Week 1	Week 4
TST (min)	476 ± 135	467 ± 146
TTIB (min)	627 ± 114	632 ± 128
SL (min)	29.6 ± 30.4	30.5 ± 32.6
SE (%)	76.1 ± 13.7	73/9 ± 17.4
WASO (min)	115.8 ± 63.6	127.1 ± 84.5
LB (no.)	2.1 ± 2.3	1.5 ± 2.2
RR (min)	16.8 ± 2.6	16.6 ± 2.3
HR (bpm)	66.7 ± 10.5	67.1 ± 10.4

Note: TST, total sleep time; TTIB, total time in bed; SL, sleep latency time; SE, sleep efficiency (the ratio of time scored as "sleep" from 'when getting into bed' to 'when getting up'); WASO, wake time after sleep onset; LB, leaving bed (total number of times leaving bed after sleep onset); RR (min), mean respiratory rate during TTIB; HR (bpm), mean heart rate during TTIB; r, multiple correlation coefficient; r^2, multiple determination coefficient.

Table 2–a is a comparison between the mean ± SD sleep related parameters during the first week (Week 1) and that of the last week (Week 4).

While no great difference was found between the pre and post parameters when comparing the average values (Table 2–a), changes in each participant were worth examining. Table 2–b demonstrates those changes between Week 1 and Week 4 in each participant. Sleep efficiency (SE, %) is the way of calculating the quality of sleep, and the ratio of sleeping time to the total amount of time staying in bed. Table 2–b shows the single correlation coefficient (r) and the single determination coefficient (r^2) between each sleeping parameter and SE (sleep efficiency). There were strong correlations between TST (total sleeping time; $r = 0.78$), SL (sleep latency time; $r = 0.83$), WASO (wake time after sleep onset; $r = 0.78$) and SE (sleep efficiency).

Multiple regression analysis was performed, with these three items (TST, SL and WASO) as explanatory variables and SE as the explained variable. A very strong correlation (0.99 as multiple r, 0.98 as multiple r^2, 0.978 as corrected r^2) was found These findings confirm that the sleep efficiency is high when the total sleeping time is longer, the sleep latency is shorter, and the total time of wake after sleep onset is smaller.

3.2. QOL measured by interRAI

Some improvements were recorded for items such as E3f (resistance to care), F5a (calming down when going out with others), F5b (participating in planned activities calmly), F5c (being invited to most group activities). However, there was no statistically significant change in care recipients' QOL evaluated by interRAI (see Table 3 for the whole list of assessment items used for the study).

3.3. Work stress and fatigue level of care professionals

The 'subjective symptoms' data collated before and after the intervention show that the fatigue levels among staff members during night shifts lowered significantly at the post-nap period ($p < 0.04$) and at the end of their shifts ($p < 0.02$) (Table 4).

The psychological state of care professionals during the night shifts improved significantly, particularly around the time when the fatigue level peaks.

3.4. Usability as perceived by care professionals

Before and after the intervention, the SUS total score associated with the SBV use increased significantly from an initial 17.6 ± 5.5 to 22.3 ± 4.8 after use ($p < 0.05$ Wilcoxon signed rank sum test) (See Appendix for the questions included in the SUS questionnaire.)

The majority of care professionals interviewed were positive towards the SBV. The reasons for the largely positive responses were primarily practical and functional. Visualisation of sleep patterns was actively utilised for checking whether care recipients were fast asleep, awake, had gone back to sleep, and/or moved away from their beds. Care staff sought to catch the moment for toileting when care recipients awoke, which reduced the number of visits to their rooms and acted as preventive measures for toileting-related incidents.

The results from the interviews are summarised in Tables 5 and 6.

On the other hand, there were some negative comments. They were all related to technical limitations of the monitor. These include the challenge of receiving multiple calls all at once, the short screen time of the image sent through the monitor, and limited capacity of Wi-fi signals.

The utility of the sleep monitors was highly rated by care professionals. Overall, there was consensus amongst care professionals over perceptions of care (person-centred care, based on the capability approach) and the importance of communication channels and tools that are shared between themselves for delivering high-quality care.

As for the communication robots, both positive and negative

Table 2
b. Difference in time and quality of sleep between Weeks 1 and 4 for participant 1–25 (the single correlation coefficient (r) and the single determination coefficient (r^2) between each sleeping parameter and sleep efficiency).

	SE (%)	TST (min)	TIBT (min)	SL (min)	WASO (min)	LB (no)	RR (min)	HR (bpm)
Participant 1	2.0	131.8	143.7	−0.2	7.6	−1.5	−0.1	16.9
Participant 2	21.3	165.1	59.3	−15.7	−91.6	−4.0	3.2	8.9
Participant 3	1.3	9.1	−0.1	0.3	−9.6	−0.7	0.0	0.3
Participant 4	12.4	25.7	−55.6	−17.9	−60.7	−0.9	−1.9	−26.8
Participant 5	11.5	69.6	2.1	−0.9	−66.6	−0.6	0.3	−2.2
Participant 6	−12.7	−61.2	11.8	5.8	67.3	2.7	−4.0	0.1
Participant 7	−1.9	−10.5	−1.4	−0.6	8.8	0.0	0.0	−1.1
Participant 8	−8.5	−73.1	−21.4	10.4	28.5	0.0	−0.3	4.9
Participant 9	2.2	−159.4	−189.2	0.1	−31.1	−0.9	−1.1	−7.8
Participant 10	−4.2	−37.9	−17.4	0.8	22.4	0.5	−0.2	4.2
Participant 11	−6.0	−48.7	−9.7	18.3	26.7	0.3	−0.3	−3.3
Participant 12	7.5	71.4	60.6	−79.9	56.4	0.1	−0.1	−2.7
Participant 13	0.5	39.6	43.0	−36.4	39.0	0.0	−0.4	−6.1
Participant 14	−18.5	−232.4	−113.3	6.9	96.0	−2.4	0.0	20.5
Participant 15	−4.8	−28.3	−19.1	12.1	−1.9	0.1	−1.1	−1.1
Participant 16	−1.9	11.1	27.4	12.9	8.4	−0.6	0.1	1.7
Participant 17	−0.5	−52.6	−55.1	1.3	−7.3	−0.7	0.5	−0.5
Participant 18	5.9	119.4	95.1	−0.6	−25.6	0.3	0.2	10.5
Participant 19	4.0	−101.8	−196.0	5.0	−95.0	−1.0	−0.7	0.0
Participant 20	−1.8	9.7	37.0	−10.6	56.6	0.0	−0.5	0.3
Participant 21	3.8	68.4	43.1	14.7	−38.1	0.0	−0.5	−1.9
Participant 22	14.2	100.6	27.1	−58.1	0.6	0.0	0.4	1.5
Participant 23	−0.6	41.6	52.3	7.0	3.4	0.0	−0.2	−1.6
Participant 24	−13.8	29.0	177.9	−5.1	130.9	−3.6	−0.1	−0.2
Participant 25	−67.6	−308.0	25.3	150.9	157.6	−1.1	0.6	−6.4
r		0.78	0.01	0.83	0.78	0.01	0.12	0.02
r^2		0.60	0.00	0.69	0.61	0.00	0.02	0.00

Table 3
Revised interRAI assessment table used in the study.

E1a	Made negative statements
E1b	Persistent anger with self or others
E1c	Expressions, including nonverbal, of what appear to be unrealistic fears
E1d	Repetitive health complaints
E1e	Frequent anxious complaints/concerns (non-health-related)
E1f	Sad, pained, or worried facial expressions
E1g	Crying, tearfulness
E1h	Recurrent statements that something terrible is about to happen
E1i	Withdrawal from activities or lack of interest
E1j	Reduced social interaction
E1k	Expressions, including non-verbal, of a lack of pleasure in life
E3a	Wandering
E3b	Verbal abuse
E3c	Physical abuse
E3d	Socially inappropriate conduct
E3e	Inappropriate public sexual behavior or public disrobing
E3f	Resisting care
E3g	Absconding or at risk of absconding
F5a	At ease interacting with others
F5b	At ease doing planned or structured activities
F5c	Accepts invitations to most group activities
F5e	Initiates interaction(s) with others
F5f	Reacts positively to interactions initiated by others
F5g	Adjusts easily to change in routine
F6a	Conflict with or repeated criticism of other care recipients
F6b	Conflict with or repeated criticism of staff
F6c	Staff report persistent frustration in dealing with person
F6d	Family or close friends report feeling overwhelmed by person's illness
O-1	Time spent alone during day
O-2	Person's willingness to initiate or participate
O-3	Average time involved in activities
O-4	Time asleep during day

comments were provided, as Table 6 suggests.

It is worth noting that there were some unintended consequences. The robots disrupted the sleep of care recipients by speaking to them at night. The very interactive aspect, which was seen as positive, created a negative impact.

Table 4
Change in total stress of care professionals during night shifts (mean ± sd) .

	before shifts	pre-dinner	pre-nap	post-nap	end of shifts
Pre-introduction	38.6 ± 9.8	46.9 ± 13.3	56.7 ± 15.3	63.4 ± 18.6	68.2 ± 17.1
Post-introduction	39.3 ± 8.5	44.4 ± 14.3	50.1 ± 16.4	56/7 ± 19.2	53.3 ± 21.7
p value	n.s.	n.s.	n.s.	$p < 0.04$	$p < 0.02$

4. Discussion

This proof-of-concept study was designed to examine the usefulness of the integrated robotics-aided monitoring system for both types of user (care recipients and care professionals). The research team viewed the effects of introducing the systemas multifaceted. The monitor records sleep patterns of care recipients, which provides a safety-monitoring function for care professionals. It also visualises what was conventionally invisible to care professionals regarding care recipients' sleeping patterns and how these could impact their behaviors on the following day or over time.

According to the findings, SBV enabled measuring of sleep parameters quantitatively, continuously and noninvasively. It became possible to record and analyse changes in the sleep quality of older persons living in the residential care home. As a result, the physical condition of care recipients, particularly during the night, can be monitored and assessed.

Although the QOL of older people did not see much improvement, the ability to track changes in the sleep efficiency and physical condition of a resident empowers care professionals with better knowledge about the care recipient. One of the weaknesses of this study was that the period of intervention might have been too short to observe much change in the participants' QOL scores. Nevertheless, some improved items (e.g. resistance to care, settled on matters with others, participating in planned activities calmly) in the interRAI scale suggest that better quality sleep could lead to further enhancement of older people's QOL, as previous studies [51,52] have shown.

In addition, the SBV combined with the Com-Robot reduced the

Table 5
Views about the monitoring sensors.

	Themes/roles of sensors	Illustrative quotes
Positive	Learning about safety-related incidents	"thanks to the introduction of the sensors, we could understand how the resident got up and stood up and why she fell" "Because we can verify and investigate incidents later."
	Providing peace of mind and preventing falls	"We actually prevented some accidents from happening."
	Providing an effective tool during night shifts, reducing stress at work	"there are only two people on the night shift, and sometimes there is one person … Then, if someone goes to the toilet frequently, and someone else gets up … we could look at the sensors, and say 'now, ah, someone's in the toilet for a long time, let's go and take a look' etc. "
Negative	Technical limitations (1) – multiple calls	"However, the difficult challenge was that there were times when you can't see all of them, as several calls come in all at once."
	Technical limitations (2) – screen time is too short	"In a few dozen seconds, the alert will disappear … I wish I could see it (the screen) for a little longer. And if there was an accident, it would cut off on the way …"
	Technical limitations (1) – dependence on Wi-Fi signal	"Someone got up, and something was up … after waiting for a while, I tried to see what was going on but I couldn't see anything, only to realise Wi-Fi was cut off …"

Table 6
Views about the communication robots.

	Themes/roles of robots	Illustrative quotes
Positive	Having something in common to talk about	"Having robots around, they became the talking point between us and the residents, which was good."
	Acting as an alarm clock that speaks at a regular time	"The robots alert residents about something … for example, 'come out to have snacks together … '
	Buying time before care staff rush to their room	"When a resident who could not press a nurse call button tried to go to toilet herself, the robot said 'is there anything wrong?' … so it buys time."
Negative	Frightening appearance	"There were residents who refused to use it, and switched it off. The robots' eyes flash, and they flash at night …"
	Very limited verbal/ communication capacity	"When the residents want the robots to listen to them, they did not hear the robot's reply, so they asked 'what is it saying?' We tried to relay the message and said 'the robot says wait a little', but the residents lost interest and did not strike up any conversation".
	Waking up residents at night	"Some residents have very good hearing, and responded and woke up to the robot's voice.

fatigue burden on staff members during their night shifts. While no qualitative data was collected to expand on care professionals' perceptions of these improvements, the statistically significant drop in fatigue levels at the time of post-nap and at the end of shifts clearly indicates the positive effects, and this merits further investigation for future research. By analysing these parameters in real time, a personalised nursing care plan for each individual can be drawn up which guarantees high-quality sleep. This will help solve one of the most troublesome problems for care professionals working in nursing care facilities, that is, older people's slips, trips and falls at night.

When an older person wakes up and tries to leave her/his bed, an alert is sent to care professionals. Therefore, the care professional in charge could prioritise visits according to urgency and the attentiveness required of the older person. Use of the technologies decreased the frequency of unexpected incontinence, and this resulted in reductions of workload and stress levels associated with night shifts.

The usability assessment, using both quantitative and qualitative methods, demonstrated that a high level of usefulness was confirmed among the participants. There may be several reasons for this. The mechanism of NemuriScan was easy to understand and the device is noninvasive for both care recipients and care professionals. The hidden nature of sleep was uncovered by the use of SBV, which might have raised the level of curiosity among care professionals. Therefore, this may not necessarily apply to other ICT equipment in care settings [52]. Despite this user-friendliness of the SBV, it is interesting to discover that users' level of 'interest in robots' and 'curiosity about new gadgets' displayed a correlation with the improvement in SBV use during the test period. This finding confirms the importance of training and education for care professionals when assistive technologies such as robots are introduced to care settings.

5. Conclusion

This study highlighted multiple (actual and potential) benefits of using the connected technologies as an integrated system in a residential care home. Measuring, recording and visibly showing the sleep parameters of older people can improve their quality of life, and also the working environment for care professionals, particularly during night-time. There is no question that the demands for high-quality care and the integration of human care and technologies will increase in the near future. The usefulness and usability of robots and assistive technologies should be further tested and measured both quantitatively and qualitatively for realising their potential in empowering care recipients and professionals towards the establishment of integrated care in the community.

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Authors' contributions

All authors participated in study design, data collection and evaluation. All contributed equally to the drafting of the manuscript and gave their final approval before submission.

Declaration of competing interest

None.

CRediT authorship contribution statement

Kazuko Obayashi: Conceptualization, Writing - original draft, Project administration, Funding acquisition. **Naonori Kodate:** Conceptualization, Methodology, Investigation, Writing - original draft. **Shigeru Masuyama:** Conceptualization, Methodology, Writing - original draft, Funding acquisition, Validation, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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Ethical approval

Ethics approval was granted by the Social Welfare Corporation Tokyo Sacramental Ethics Committee (TS 2017-002). Consent was sought from each participant and their family. The research was conducted between December 2017 and January 2018.

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