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Biodynamic light to support ageing in place for people living with dementia: An explorative longitudinal single-case experimental design in three persons

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Abstract

Background: Worldwide, people ageing in place become the new normal. For people with dementia, ageing in place is not that self-evident. Behavioural and psychological symptoms of dementia like aberrant motor behaviour are often associated with placement in long-term care facilities. Nowadays mental health care not only focuses on intramural care but also provides personalized care and support for community-dwelling people with dementia. Mental care and support in a home setting could be difficult, fortunately, assistive technology has great potential in fostering independent living and improving mental and physical health. Biodynamic lighting could be a promising technological innovation for home use to support people with dementia.
Objective: This study explores the influence of biodynamic lighting on aberrant motor behaviour over time in people living with dementia at home.
Method: This study uses an A-B-A-B withdrawal single-case experimental design of three persons living at home with dementia.
Results: Although differences between biodynamic light and placebo light with respect to aberrant motor behaviour did not reach significance, a trend was seen in the stabilization of aberrant motor behaviour over time. All participants subjectively reported positive effects of the biodynamic light.
Conclusion: As this research was merely explorative, future research should examine whether this intervention contributes to ageing in place for people living with dementia. However, this study showed that it is feasible to adopt these kinds of interventions in a home situation.

Keywords: dementia, neuropsychiatric symptoms, healthy ageing, light therapy, single case experimental design, non-pharmacological

Introduction

With an increasingly ageing population, policy agendas often address the concept of healthy ageing (Drewnowski et al., 2003). Healthy ageing is about adding healthy years to the lives of older people (Zaidi et al., 2017). One aspect of healthy ageing is ageing in place. The underlying idea of this concept is that helping people stay at home longer, contributes to enhanced well-being, and independence and eventually helps when it comes to healthy ageing (Sixsmith & Sixsmith, 2008). For ageing in place, prevention is important. Prevention comprises all interventions to avoid evil happenings, diseases, threatening circumstances, adverse ageing effects (primary prevention), and once unwanted effects have manifested themselves nevertheless, to avoid further deterioration and diminish impacts and negative side effects on daily life (Bouma, Taipale & Van Bronswijk, 2015).

Cognitive disorders might threaten both ageing in place and the healthy ageing of older people, as it affects the lives of people with such disorders and their social environment (i.e., informal caregivers, family, friends, etc.). Dementia is one of the most common cognitive disorders. The behavioural and cognitive changes in the person with dementia result in difficulties in living independently. As there is currently no cure for dementia, more attention is needed to personalized support for people living with dementia at home. This transition of ageing in place with dementia is setting a new standard in mental health care.

In order to achieve this, it is necessary to manage Behavioural and Psychological Symptoms of Dementia (BPSD), also known as neuropsychiatric

(a)

(b)

Figure 1. (a) The Sparckel, type Bright Brenda; (b) The Sparckel, type Jolly James

symptoms. BPSD are a heterogeneous group of non-cognitive symptoms and behaviours. This includes agitation, aberrant motor behaviour, anxiety, elation, irritability, depression, apathy, disinhibition, delusions, hallucinations, and sleep or appetite changes (Cerejeira, Lagarto, & Mukaetova-Ladinska, 2012). BPSD affect 80-100 percent of all people with dementia at some point during the progression of the disorder (Eikelboom et al., 2021; Vik-Mo et al., 2018; Brodaty et al., 2015; Aalten et al., 2005; Fernández-Martínez et al., 2008). Severe BPSD is commonly reported at the time of the diagnosis (Vik-Mo et al., 2018). They cause immense patient suffering, have a great impact on the quality of life of both patients and primary caregivers, and are responsible for caregiver distress (Feast et al., 2016; Haaksma et al., 2017; Hiyoshi-Taniguchi, Becker, & Kinoshita, 2017; Truzzi et al., 2013; Trigg et al., 2015). BPSD are also a strong predictor of institutionalisation and hospitalisation (Brodaty et al., 2014; Gaugler, Krichbaum & Wyman, 2009). Finally, the presence of a high level of BPSD is a risk factor for death within three years (Tun et al., 2007).

Aberrant motor behaviour (AMB) is one of the BPSD which causes the most distress (Feast et al., 2016) and burnout (Hiyoshi-Taniguchi, Becker & Kinoshita, 2017) to the informal caregiver. AMB includes pacing around the house without apparent purpose, doing things repeatedly such as opening closets or drawers, picking at things, or winding strings or threads (Cummings et al., 1994). The prevalence of AMB in patients with dementia is 23-45 percent (Aalten et al., 2005; Fernández-Martínez et al., 2008; Truzzi et al., 2013; Zhao et al., 2016; D'Onofrio et al., 2012) and is one of the most commonly reported symptoms during the course of the disease (Vik-Mo et al., 2018). Additionally, AMB increases over the course of the disease (Eikelboom et al., 2021; Brodaty et al., 2015; Aalten et al., 2005). Scarmeas et al. (2007) found that wandering was the strongest predictor of functional decline and institutionalisation.

Clinical practice guidelines on management of dementia advise to start with non-pharmacological interventions first, and only if these non-pharmacological interventions fail, initiating medication (Azermai et al., 2012). There is increasing evidence for the effectiveness of various non-pharmacological interventions (Overshott, Byrne & Burns, 2004; Dyer et al., 2018). An example of a promising non-pharmacologic intervention is light therapy. Positive effects of bright light were found in institutionalised people with dementia on diverse BPSD (e.g. Riemersma- van der Lek et al. 2008; Figueiro et al. 2014; Burns et al. 2009; Rubiño et al. 2017). In a systematic review, Mitoloa and colleagues (2018) suggest that the effects of light treatment on people with Alzheimer's disease in general trend

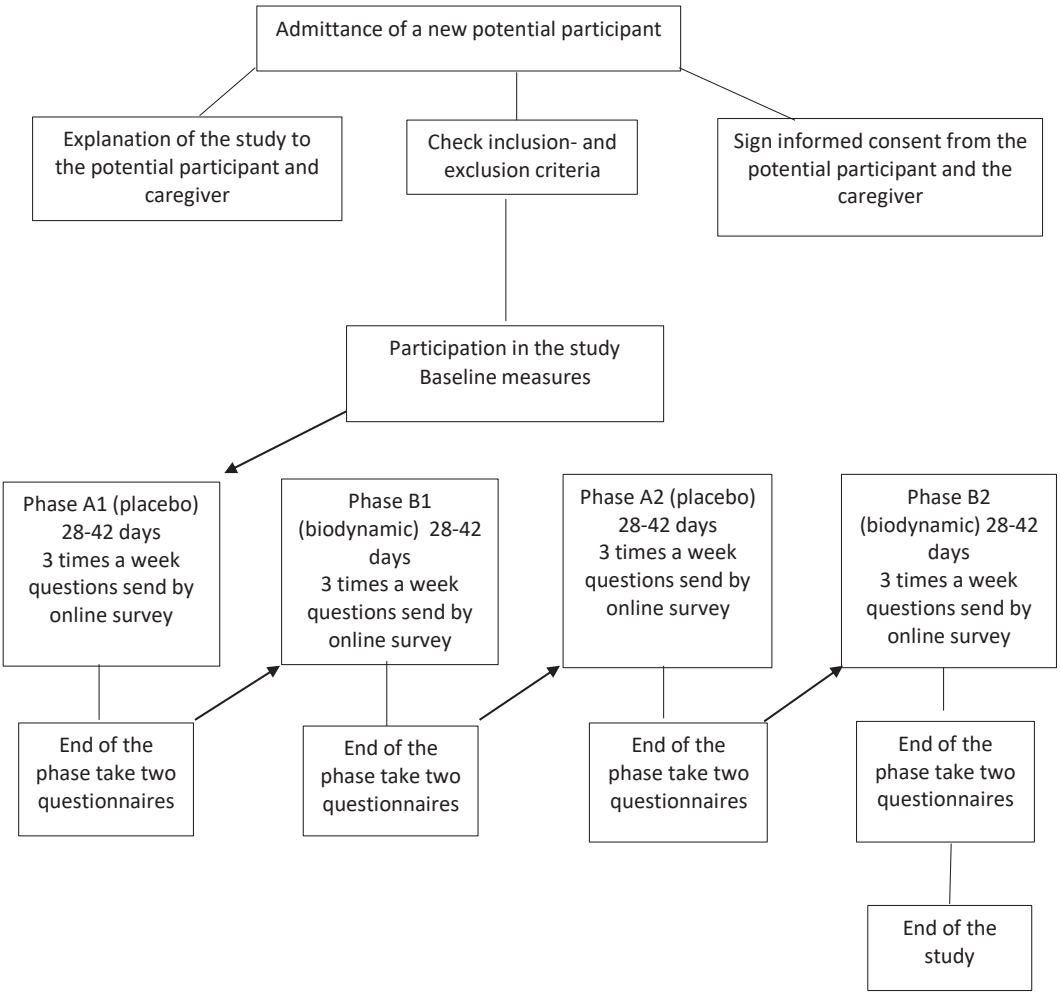


Figure 2. Schematic representation of the research design

toward a positive effect on sleep, cognition, and mood. Similar results were found in recent reviews among older people with cognitive impairment in sleep, mood, and behaviour (Cibeira et al., 2020; Goudriaan et al., 2021).

Research on the effects of light on motor behaviour (e.g. bradykinesia, balance, and rigidity) in people with Parkinson's disease showed positive effects. Bright light therapy resulted in improved motor function in most patients, with the strongest effects on bradykinesia and rigidity. After bright light therapy, dopamine replacement therapy was reduced to a level ranging from 13 to 100 percent. Additionally, adherent patients displayed a significant improvement in bradykinesia, rigidity, balance, and motor tests, while motor parameters in the group, that withdrew from bright light therapy immediately after intake, deteriorated over time (Rutten et al., 2012; Willis & Turner, 2007; Willis, Moore & Armstrong, 2012). To our knowledge, no study has investigated this relation in people with dementia yet.

As people age, the eyes and brain often become more affected (Aries, van der Vries & Westerlaken). Because of the increased sensitivity of the ageing eye to discomfort glare and blinding by light, standard light therapy methods are not suitable for older adults (Konis, Mack, and Schneider, 2018). Also, regular indoor light is no longer sufficient for the stimulation of the suprachiasmatic nucleus (SCN). To have an effect on the SCN, it is suggested that the intensity of light needs to be ±1000 lux (Riemersma- van der Lek et al., 2008; Middleton, Stone & Arendt, 2002). Visual acuity and colour contrast naturally diminish with age, but dementia often has major effects on the visual processing systems, which has a negative impact on the quality of life (Wulff & Foster, 2017). For light therapy to be effective, the visual limitations of an older person need to be taken into account. Biodynamic light therapy is a specific kind of light therapy. In biodynamic

Table 1. Participant characters at baseline

	Participant one	Participant two	Participant three
Gender	Male	Female	Female
Age	66	67	84
Diagnosis	Alzheimer's disease	Vascular dementia	Alzheimer's disease + Parkinson's disease
Education	Primary technical school	Middle school	Domestic science school
Former work	Truck driver	Interpreter	Domestic help
Marital status/ living situation	Married, living with his wife	Widow, living with her daughter and her family	Married, living with her husband
Medication	Asasantin Reminyl Rosuvastatine aurobindo	Mylan Acetylsalicylzuur Omeprazol	Lisinopril Madopar Quetiapine Omeprazol Simvastatine Mirtazepine Lormetazepam
Amount of lux in living room ('normal lighting')	86 lux in the living room; 190 lux near the window	110 lux in the living room; 547 lux near the window	121 lux in the living room; 410 lux near the window
Informal caregiver	Wife	Daughter	Husband
Mini-Mental State Examination Scores (impairment)	19/30 (moderate)	19/30 (moderate)	20/30 (moderate)
AMB problems at start	Scratching Pluck dog hair Aimlessly messing around in the house	Trying to walk away Accosting people	Aimless wandering Open and close drawers

light (BDL), the light intensity and colour varies during the day and resemble the intensity and colour of natural daylight. A recent review by Jao et al., (2022) on the effect of ambient bright light on BPSD revealed the positive effect of this specific light on depressive symptoms and agitation in persons with dementia. Another study, by van Lieshout-van Dal, Snaphaan & Bongers (2019a), found promising evidence that BDL could be helpful in decreasing sleeping disturbances in patients with dementia. Our previous published article on the effects of BDL on activities of daily living (ADL) showed no significant effect on ADL over a 5.5-month period, but we saw a stabilisation of the ADL problems experienced over time (Aarden-van Delft, Peeters, & Snaphaan, 2021).

To our knowledge, there is no research yet on the effects of BDL on motor behaviour in people with dementia. The aim of this study was to assess the study protocol and the implementation of BDL in the home setting for people with dementia. Subsequently, an exploration of the possible influence of BDL on AMB was assessed in three patients with dementia living at home. It was hypothesised that exposure to biodynamic lighting during the day will have a positive effect on AMB.

Methods

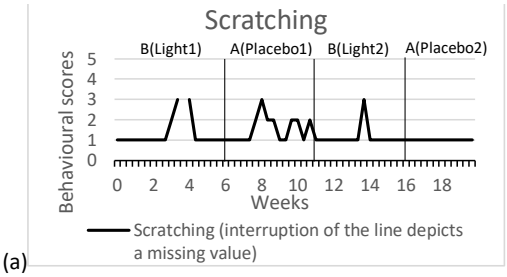
This study is based on the same study protocol as described in a recent publication by Aarden-van Delft et al. (2021). Whereas previous research focuses on evaluating the protocol based on the outcome variables of ADL, this study investigates the relation between dynamic light and AMB. For a detailed explanation of the single-case experimental design (SCED), setting, participants, and intervention of this study, we refer to the article of Aarden-van Delft et al. (2021) and the supplementary file. Below you find a summary of the used methods.

Research design

The Biodynamic Light used in this study comes from the Biodynamic Light System Sparckel, type 'Bright Brenda' and 'Jolly James' (*Figures 1a and 1b*). The Sparckel is a BDL system that can easily be used in a home situation and has been developed after extensive research in a co-production with lighting specialists and end users (van Lieshout-van Dal, Snaphaan & Bongers, 2019a). More details about the light specifications can be found in an article by Aarden-van Delft et al. (2021).

In this study, both the biodynamic light and the placebo light are from the same light system. In the placebo phases (A1 and A2) placebo light was offered, and in the intervention phases (B1 and B2) BDL from the same light system was offered. The length of the phases was randomly assigned for each subject separately so that the internal validity of the research would be increased (Kratochwill & Levin, 2010). A phase lasted a minimum of four weeks and a maximum of six weeks.

Before the light system was turned on, we carried out a context analysis for mapping participant characteristics, by using the Mini-Mental State Examination (MMSE) (Folstein, Folstein & McHugh, 1975) and the Neuropsychiatric Inventory (NPI) (Cummings et al., 1994). The MMSE was only taken at baseline and was used for the screening of cognitive impairment. It includes 11 questions. The test evaluates the following cognitive functions: attention and orientation, memory, registration, calculation, language, and praxis. A low



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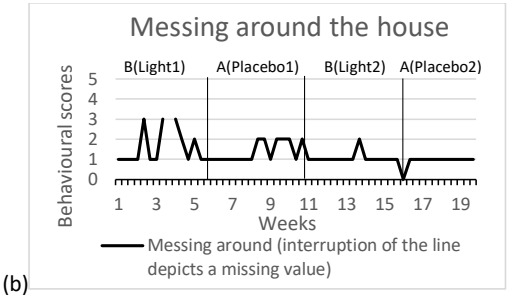

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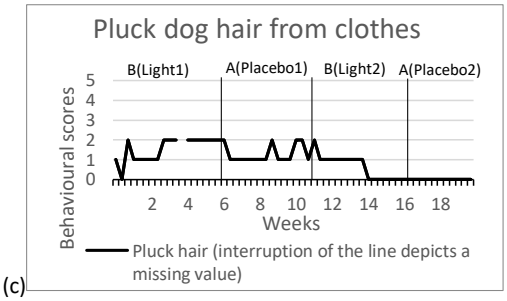


(c)

Figure 3. (a) Scores scratching; (b) Scores messing around the house; (c) Scores pluck dog hair form clothes

score on the MMSE corresponds to low cognitive functioning Folstein, Folstein & McHugh, 1975).

The NPI is an instrument to assess 12 behavioural disturbances occurring in dementia patients: delusions, hallucinations, dysphoria, anxiety, agitation/aggression, euphoria, disinhibition, irritability/lability, apathy, aberrant motor activity, nighttime behaviours, and appetite/eating (Cummings et al., 1994). It is an objective and valid instrument for assessing various changes in behaviour and psychological functioning in dementia; it has a between-rater reliability kappa >0.90 and construct validity R= 0.35-0.60 (Kat et al., 2002). The NPI was assessed at baseline and at the end of every phase with the informal caregiver to provide insight into the total amount of BPSD of the participant and their course over time.

In each phase of the study, the informal caregiver answered three times a week various questions about AMB of their loved one via the online survey 'Positive Perception Program' (PPP). PPP is an online survey used to (subjectively) measure the received light during the day and the AMB outcomes such as wandering, aimless behaviour and motor unrest. The participants' caregivers are asked to answer questions about the amount of light the participants have received through the light system in the morning and the evening, and how long they have been outside. For example, 'how many minutes of light through the lamps has your partner received between 09:00 and 12:00 o'clock in the last two-three days?'. A maximum of nine questions about AMB are then asked. For example, 'how often is he/she wandering aimlessly around the house in the last two or three days?'. All questions about AMB have a maximum of six answer categories to answer. Answer category 0 is 'not at all', 1 is 'less than once a day', 2 is 'once a day', 3 is 'two-three times a day', 4 is 'four-five times a day' and 5 is 'over five times day'. After context analysis, the placebo light in phase A1 was turned on for 28 to 42 days, depending on the predetermined random assignment. The light system was on all day. After phase A1, the BDL for phase B1 was turned on. This light change was repeated for phases A2 and B2. A home visit was planned at the end of every phase to administer the NPI and switch the light systems to the other light. A schematic representation of the research design can be found in *Figure 2*.

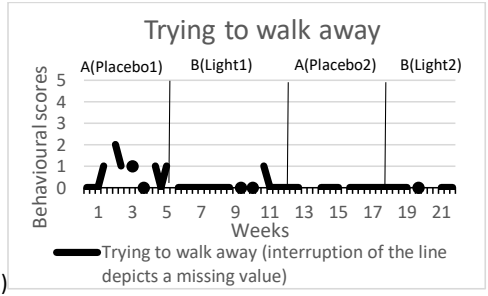
Study population

The recruitment is based on the previous study by Aarden-van Delft et al. (2021). A total of four participants with dementia, living at home with an informal caregiver were recruited. Dementia is diagnosed in terms of Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5) (American Psychiatric Association, 2013). Three of them met the inclusion criteria: age above 65, living at home with an informal caregiver, and a frequency score of at least three on the Neuropsychiatric Inventory (NPI) (Cummings, 1994) item 'Aberrant Motor Behaviour' (frequently, several times per week, but less than every day). Exclusion criteria for this study were: ocular/visual problems, e.g. ophthalmic abnormality that greatly impedes light perception, e.g. dense bilateral cataracts, pre-existing (severe) psychiatric problem (e.g., bipolar disorder, psychosis), incapacitation according to an objective expert, bedridden and palliative treatment or terminally ill. The main characteristics of each of the three participants (persons with dementia) are listed in *Table 1*.

Data analysis

For analysing the data obtained from PPP, we used Randomisation tests (RTs).

To carry out the RTs, the Shiny app for Single-Case Data Analysis, Shiny SCDA (https://tamalkd.shinyapps.io/scda/ , accessed on 20 July 2021)



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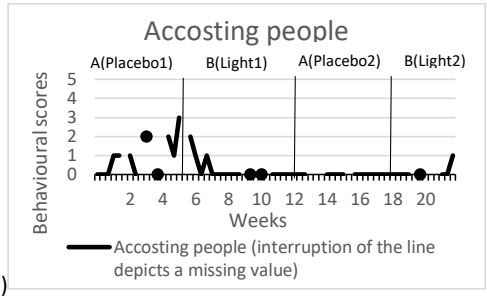

(b)

Figure 4. (a) Scores trying to walk away; (b) Scores accosting people

was used. The web app implements functions contained in SCRT (Single-Case Randomisation Test), SCVA (Single-Case Visual Analysis), and SCMA (Single-Case Meta-Analysis) R packages (Bulté and Onghena 2013).

To determine whether there are differences in the amount of light received from the light system in the morning and evening, the Wilcoxon Signed ranks test was performed with the Statistical Package for Social Sciences version 26. All p-values below 0.05 were considered significant. Microsoft Excel was used to visually analyse the results of the assessment of the NPI.

Institutional review board statement

This study was conducted according to the guidelines of the Declaration of Helsinki. Ethical approval for this explorative study was obtained from the local science committee of the mental health care organisation Eindhoven, The Netherlands (IMBB/2018025). They checked the local practicability and the burden of their patients and healthcare professionals. All subjects gave their informed consent for inclusion before they participated in the study.

Results

The data collection took place between December 2018 and October 2019. All three included participants completed all phases of the study. The main characteristics of each participant at baseline are illustrated in *Table 1*, as well as their cognitive status (MMSE), level of BPSD (NPI), type of AMB, and normal light level at baseline without a light system. We collected 60 data points for participant one with a response rate of 98.3 percent. For participants two and three, 66 and 59 data points were collected, respectively, with cohesive response rates of 75.8 percent and 79.6 percent. No significant changes in medication were reported during the study.

Every participant received an equal amount of light minutes during the day in the placebo phase and the intervention phase. The number of minutes of light received in all phases from the light system in the morning (9-12 am) was significantly less than the amount of minutes of light received from the light system in the evening (7-11 pm) for all three participants. This means that for the intervention phases each participant received in total more amber/red light with a low intensity than blueish/white light with a high intensity. More details about the amount of light can be found in the boxplots in the article by Aarden-van Delft et al. (2021) (*Figures 5 and 6*) and in the supplementary file.

Participant one

Relation of BDL on AMB

Statistical analyses show that none of the aberrant motor behaviours in participant one is significantly lower in the intervention phase with BDL compared to the placebo phase (scratching $p = 0.09$, aimlessly messing around in the house $p = 0.14$ and plucking dog hair from clothes $p = 0.60$). Visualisation of the scores is presented in *Figure 3*. These behaviours are scored on a range from 0 = not present to 5 = present more than five times a day. Due to unforeseen circumstances, the first phase became a 'B' phase instead of an 'A' phase. After the last B phase, we inserted an extra A phase, so that there were still four phases for analysis.

Subjective evaluation of BDL in a home setting

Participant One and his informal caregiver rate the light and the light system positively. They report a subjective improvement in AMB, especially in scratching. At the end of the study, they indicate that they themselves consider purchasing a lamp with BDL, although one which is less expensive.

Participant two

Relation of BDL on AMB

In participant two, phase B1 lasted 24 days instead of the minimum intended 28 days, due to a vacation (in the same time zone and a country with the same climate as in her home environment). Statistical analyses show that none of the aberrant motor behaviours in Participant 2 are significantly decreased by BDL (trying to walk away $p = 0.45$, accosting people $p = 0.75$). Visualisation of the AMB is presented in *Figure 4*. These behaviours are scored on a range from 0 = not present

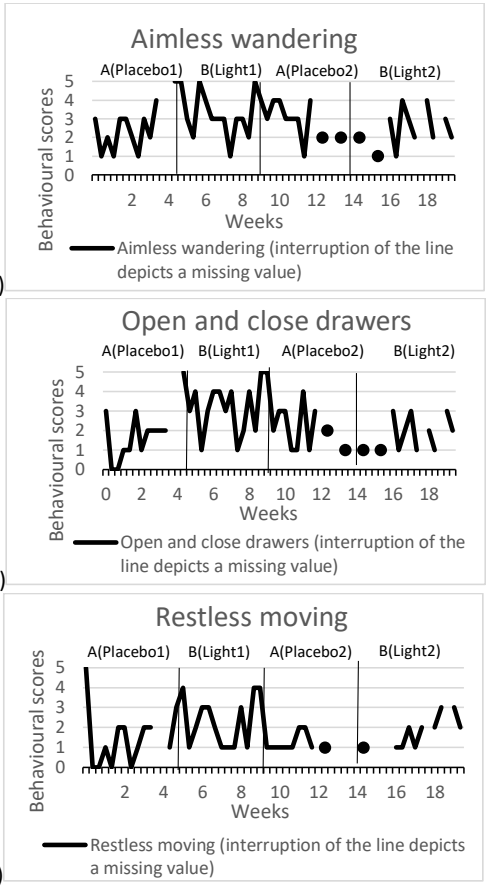

Figure 5. (a) Scores aimless wandering; (b) Scores open and close drawers; (c) Scores restless moving

to 5 = present more than five times a day.

Subjective evaluation of BDL in a home setting
Participant Two and her informal caregiver also rated the light positively, in particular in the winter period. BDL is chosen over placebo light. They are considering purchasing a BDL system.

Participant three
Relation of BDL on AMB
Statistical analyses show that none of the aberrant motor behaviours in participant three are significantly decreased by BDL (aimless wandering p = 0.29, open and closing drawers p = 0.48, and moving hands and feet restlessly p = 0.98). Visualisation of the AMB is presented in *Figure 5*. These behaviours are scored on a range from 0 = not present to 5 = present more than five times a day.

Subjective evaluation of BDL in a home setting
The informal caregiver of participant three thinks that his wife was calmer in behaviour with the light system on. They have no preference for any of the types of light. They find the light system easy to use.

AMB course over time for three participants
Based on the results of the NPI questionnaire at the end of each phase (baseline, phase one, phase two, phase three and phase four), *Figure 6* shows the total score of AMB of all three participants. By visual analyses of Figure 6, we can see a decrease in AMB over time in Participants One and Two and a stabilisation in Participant Three.

Discussion

As there is currently no cure for dementia, more attention is needed to personalized support for people living with dementia at home. This transition of ageing in place with dementia become a new normal in mental health care. Technological innovations are seen as a potential resource to facilitate or improve ageing in place. The aim of this explorative longitudinal SCED study of three participants was to investigate the possible influence of BDL on AMB for community-dwelling people with dementia and the feasibility of such technological innovation as BDL could be adopted in the home setting. Earlier studies found positive effects of (biodynamic) lighting on psychological behaviour in older people. For example, Wahnschaffe et al. (2017) and van Lieshout-van Dal, Snaphaan, Arkink & Bongers (2019b) found a positive relation between dynamic lighting and reducing BPSD in dementia, mainly non-physically aggressive behaviours, which include restlessness, repetitious mannerisms, and pacing. Positive effects of bright light on motor behaviour were also found in people with Parkinson's disease Rutten et al., 2012; Willes & Turner, 2012; Willis, Moore & Armstrong, 2012). We hypothesised that exposure to BDL could reduce AMB in community-dwelling people with dementia.

In this explorative longitudinal pilot study, we found no significant decrease in AMB due to BDL exposure. However, qualitative results showed a stabilisation or even improvement of AMB over a 5.5-month period. The same pattern can be seen in the same study population on Activities of Daily Living (ADL) (Aarden-van Delft et al., 2021). These qualitative results were related to the non-pharmacological intervention light, more specifically low-intensity light or amber/red light during the evening, because participants significantly consume more light from the light system in the evening instead of the morning. Van Lieshout-van Dal et al. (2023) found an effect of biodynamic light on depression and agitation in home-dwelling people with dementia. In addition, this study shows that adoption of this kind of technology for a longer period in a home setting is high. Participants assess the light and light system positively and therefore BDL is well suited for community-dwelling people living with dementia for 3.5 - 5.5 months.

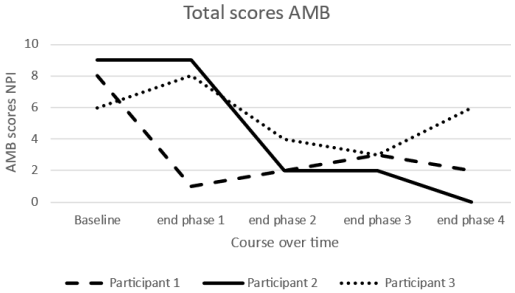

Figure 6. NPI scores of AMB over time of all three participants

Because of the neurodegenerative nature of dementia and no changes in medication during the study, an increase in symptoms in AMB is expected without intervention, within three to six months (Brodaty et al., 2015; Chung & Cummings, 2000; Tschanz, 2011). Therefore, our findings are very supportive of the transition of ageing in place with dementia as the new normal for mental health care. Further research is needed to see the longitudinal effects of BDL and AMB and to identify the amount and type of light which is needed to stimulate motor behaviour.

This, together with a study by van Lieshout et al. (2021, 2023), is to our knowledge, one of the first studies to investigate the effects of BDL in the home situation of people with dementia instead of in a controlled setting. Currently, SCED instead of a randomised controlled trial is more appropriate, because this design makes it possible to investigate individuals, without aggregating data, and is in line with the clinical relevance of this research to efforts to support people with dementia at home. This design has the ability to obtain data from one specific participant. In our case, we collected data three times a week, which is valuable for investigating the pattern of AMB per person over time, even if the changes are relatively small. Therefore, the improvement or stagnation of AMB could be seen at an individual level without aggregating data.

The frequency of three times a week turned out not to be invasive for the participants, partly due to the user-friendly manner of data collection via the PPP program, as reflected by the high response rate and the positive responses of the participants at the end of the study. The A-B-A-B design, suggested by the What Works Clearinghouse (Kratochwill et al., 2010), is a design that can be randomised, and offers the opportunity to obtain sufficient measurement moments. This design requires a minimum of four A and B phases, such as the A-B-A-B design. To maximise the chance of identifying an effect, Van der Ploeg and O'Connor's (2014) recommendations have been followed, such as mapping cognitive function and dementia diagnoses at baseline, excluding participants with known ophthalmic abnormalities, measurements of baseline available light levels and a control condition that tests another type of light.

Although there is no statistical evidence of the relation between BDL on AMB, the user experiences of BDL are positive, and the adoption of the technology seems high. All participants rated the light and the light system positively. They kept the light systems on during the day for a longer period, despite the unnaturalness of using a light system when the sun was shining. A (subjective) improvement in AMB was reported by all three caregivers. Finally, two of the participants indicated that they themselves considered purchasing a lamp with BDL. Regarding technology acceptance by independent-living seniors, Peek et al. (2017) stated that this can best be characterised as a heterogeneous process with many different origins, pathways, and consequences. Technologies that are acquired in ways that are not congruent with seniors' personal needs and circumstances run a higher risk of proving to be ineffective or inappropriate. Our study warrants investigating further whether light technology could be a non-pharmacological intervention to support people with dementia at home.

Some limitations have to be considered. This study investigates whether people are willing to collaborate in this kind of non-pharmacological intervention. Awareness of light therapy is very low in people living with dementia, so a deliberate decision was made to use a design that is less intrusive for the participants (e.g. without lots of sensors). This study did only subjectively measure how much light (intensity and colour spectrum) the participants received. Although statistical analyses indicate that there is no significant difference in time spent around the light system and the time spent outdoors, these data still do not guarantee that people consume less lux in the placebo condition than in the intervention condition. For future research, it is highly recommended to use a sensor, that can objectively and continuously measure the amount of lux and colour spectrum during the day. One could argue that there are differences between the summer period and the winter period. This makes the effect of light from the light system less visible. However, due to the chosen A-B-A-B design, the two placebo phases fell at two different seasons. In the comparison between the different conditions, the possible effects of the different seasons are included.

Also, the amount of lux of the placebo light used in this study (~200 lux) is higher than the regular daily light (baseline) to which the participants are normally exposed. It could be that this amount of

lux was too high as placebo light with the result that it negated the positive effects of the intervention (Hjetland et al., 2020). Therefore, a third phase of baseline light should have been taken into account. On the other hand, it is also possible that due to this study design, in some cases, a lower amount of lux instead of the suggested 1000 lux from the literature (Riemersma-van der Lek et al., 2008; Middleton, Stone & Arendt, 2002) could also have an effect on the stabilisation of AMB problems in people with dementia.

Another limitation is that this study investigates the occurrence of AMB during the day, whereas restless motor behaviour often occurs at twilight, which is called sundowning (Bliwise et al., 1993; Burney-Puckett, 1996). Sundowning can be a result of a dysregulation of the suprachiasmatic nucleus, which causes a disturbance of the circadian rhythm (Bliwise et al, 1993; Khachiyants, Trinkle, Son & Kim, 2011). A decreased ability to maintain a stable circadian pattern of daytime arousal and nocturnal quiescence may contribute to behavioural disturbances in persons with dementia (Forbes et al., 2014). Despite the fact our study protocol did not explicitly take the sundowning effect into account, we still see a trend of an overall stabilisation of AMB.

Future research should focus on the type and amount of light and on what time of the daylight should be offered. Therefore, it is important to investigate what kind of light can be used in the home setting as a therapeutic intervention. In contrast to bright light, BDL is more appropriate for a home setting. The main benefits of BDL used in our study are that it can be used all day, it is transportable, easy to use, and can assist an individual with their activities during the day based on a personal light plan. This makes BDL very suitable for research in the home situation.

Conclusions

In conclusion, there is no significant effect of BDL on AMB in community-dwelling people with dementia. However, the light protocol used in this study might stabilise AMB in a time period of 5.5 months. These findings seem supportive of the transition of ageing in place with dementia as the new normal for mental health care. This technology could be adopted by people with dementia and their informal caregivers when treatment at home is needed.

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Appendix

Design

This in-context field study used a longitudinal A-B-A-B withdrawal SCED. This design involved two conditions: a placebo condition with two phases (A1 and A2), with light from the light system, and an intervention condition with two phases (B1 and B2), with BDL from the same light system.

Placebo light provided by the light system was chosen, instead of the 'normal' lights of the participant, in order to blind the participants as much as possible to the difference in conditions. The length of the phases was randomly assigned for each subject separately so that the internal validity of the research would be increased (Kratochwill & Levin, 2010). The literature shows it takes about two weeks to adjust the biological clock in people with dementia (Sekiguchi, Iritani, & Fujita, 2017).

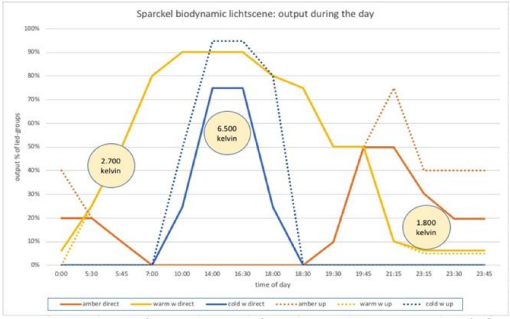

Figure 7. Biodynamic colour temperatures of the Sparckel during a day

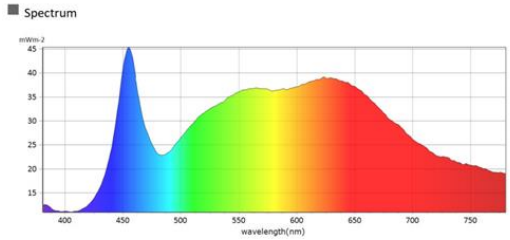

Figure 8. Spectrum analysis of BDL

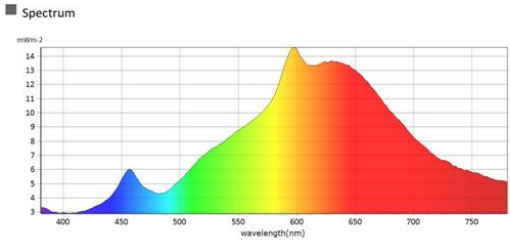

Figure 9. Spectrum analysis of placebo light

Therefore, we have deliberately chosen to extend the phases by 14–28 days. Each phase lasted between 28 and 42 days. Before the study started, the length of each phase was randomly determined using the Research Randomizer program provided by the Social Psychology Network (http://randomizer.org, accessed on 20 July 2021).

At baseline (T0), we carried out a context analysis for mapping participant characteristics. This analysis included questions about demographics, observations and a cognitive screening (MMSE). In each phase of the study, the informal caregiver answered a couple of questions (approximately 5–10 min) three times a week via the online survey 'Positive Perception Program' (PPP) on their hand-held device or computer and received questions at predetermined times about AMB about their loved one. After context analysis, the placebo light in phase A1 was turned on for 28 to 42 days, depending on the predetermined random assignment. The light system was on all day, but participants were only asked about the amount of light they received in the morning and evening, as they were often absent during the day. After phase A1, the BDL for phase B1 was turned on. This light change was repeated for phases A2 and B2. A home visit was planned at the end of every phase to administer the Neuropsychiatric Inventory Questionnaire (NPI) and switch the light systems to the other light.

Setting

The study was conducted at the homes of the participants for, respectively, approximately 4.5, 5.5 and 4.5 months, with the same researcher for the entire track. The light systems were put in place(s) where the person with dementia spent most of his or her time.

Participant One: needed one light system and was placed next to the chair he was sitting in most of the day (starting with breakfast until he goes to bed). For participant two, two light systems were placed, one next to the chair she was sitting in most of the day when she was at home. The other light system was placed next to the table where she ate her meals. For participant three, two light systems were placed, one next to the chair she was sitting in most of the time when she was at home. The other light system was placed on the table where she ate her meals.

Positive perception program

Positive Perception Program (PPP) is an online survey consisting of two parts and is used to subjectively measure the received light during the day (part one) and AMB outcomes, such as wandering, aimless behaviour and motor unrest (part two). In the first part of the survey, the participants' caregivers are asked to answer ques-

Table 2. Measurement data of one lamp from Olino measurement report

Parameter	Lamp measurement	Remark
Colour temperature	4847 K 4750 K	Direct light Indirect light
Light intensity	1984.2 Cd	0,1 m distance
Colour Rendering Index	87	CRI_Ra
S/P ratio	2.0	1 m distance
Melanopic Effect Factor	0.682	According to standard DIN SPEC 5031-100:2015-08
Light spectrum	465–480 Nm	Melanopic lux
Luminous Flux	6818l m	1 m distance
Blue light hazard risk	Group 0	No risk

tions about the amount of light the participants have received through the light system in the morning and evening and how long they have been outside. For example, 'How many minutes of light through lamps has your partner received between 09:00 and 12:00 in the last 2–3 days?'. The second part contains (a maximum of) nine questions about AMB. For example, 'how often is he/she wandering aimlessly around the house in the last two-three days?' or 'how often does he/she use repetitive sentences or questions?' in the last 2–3 days?'.

There are a maximum of six answer categories to answer these questions. Answer category 0 is 'not at all', 1 is 'less than once a day', 2 is 'once a day', 3 is 'two-three times a day', 4 is 'four-five times a day' and 5 is 'over five times day'. This online survey was sent to the informal caregiver by the PPP program (www.ppp-zorg.nl, accessed on 20 July 2021) three times a week. The informal caregiver rated all questions and interviews about their loved ones.

Light

The intervention in this study is BDL. A fixed day curve program for BDL was installed and used in our study. One lamp produces 1000–7500 lumen, five times more than is usual in a living room. The spectrum of the BDL simulates a regular daylight curve by following this curve in light colour and intensity. In the morning, the light system produces direct and indirect light with a high illuminance and bluish colour. In the evening, the light has lower levels of illuminance (more red in colour). The topside of the lamp produces indirect light and contains 12 high power LED lights producing a maximum of 3 W per piece. It consists of four lights producing 6500 K, four lights producing 2700 K and four lights producing 1800 K. The bottom side produces direct light and contains 196 medium power LED lights producing a maximum of 3 W per piece. It consists of 98 lights producing 6500 K, 49 lights producing 2700 K and 49 lights producing 1800 K. The correlated-colour temperature (CCT) is 4600 K. Please see *Figures 7, 8, 9, 10, 11,* and *Table 2*.

The placebo light used in this study also comes from the Sparckel systems and has a stable intensity (~200 lux, CCT is 2700 K) and colour throughout the day. In addition, participants were also allowed to use their regular light indoors at all times.

Perceived amount of light

The median is demonstrated as the 'X' within the boxplot. The length of the boxplot represents the interquartile range, and the boxplot whiskers are 1.5 times the interquartile range. All data points outside the whiskers are considered outliers. (Cluster 1 = 0–30 min light per day; cluster 2 = 30–60 min light per day; cluster 3 = 60–90 min light per day; cluster 4 = 90–120 min light

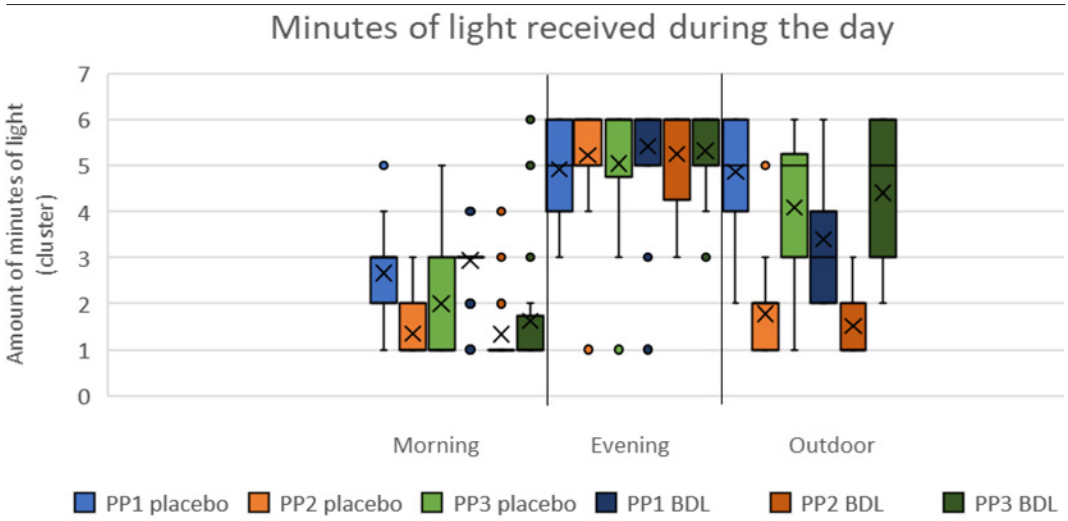

Figure 10. Boxplots of minutes of light received in the morning, evening and outdoor

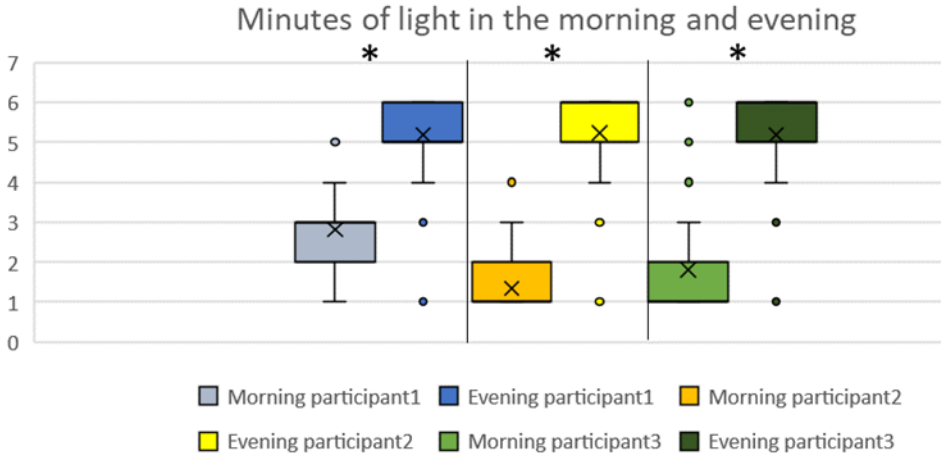

Figure 11. Boxplot of minutes of light received in the morning and evening per participant

per day; cluster 5 = 120–150 min light per day; cluster 6 ≥ 150 min light per day). Randomisation tests showed no significant difference between morning, evening and outside ($p > 0.05$).

The median is demonstrated as the 'X' within the boxplot. The length of the boxplot represents the interquartile range, and the boxplot whiskers are 1.5 times the interquartile range. All data points outside the whiskers are considered outliers. (Cluster 1 represents 0–30 min light per day; cluster 2 represents 30–60 min light per day; 3 represents 60–90 min light per day; cluster 4 represents 90–120 min light per day; cluster 5 = 120–150 min light per day; cluster 6 ≥ 150 min light per day). * = Wilcoxon Signed ranks test significant difference between morning and evening ($p< 0.001$). The questions regarding the perceived amount of light are as followed:
(1) How many minutes of light through the lamps has your partner received between 09:00 and 12:00 o'clock in the last two-three days?
(2) How many minutes of light through the lamps has your partner received between 19:00 and 23:00 o'clock in the last two-three days?
(3) How many minutes spent your partner outdoor in the last two-three days?

All three questions are multiple choice, with six answer categories: 0-30 minutes per day; 30-60 minutes per day; 60-90 minutes per day; 90-120 minutes per day; 120-150 minutes per day; > 150 minutes per day.

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