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Biodynamic Lighting and Functional Disability; a Single-Case Experimental Design in Three Community Dwelling People with Dementia

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Abstract: Functional disability in people with dementia is associated with placement in long-term care facilities, feelings of depression and caregiver burden. As there is currently no cure for dementia, more attention is needed for personalised support for people living with dementia at home. A promising non-pharmacological innovation for reducing problems in functional activities is biodynamic lighting. This type of artificial lighting resembles a normal daylight curve, including changes in light intensity and colour during the day. The aim of this pilot study with three participants is to explore the possible influence of biodynamic lighting on functional activities over time on people with dementia living at home. The study used an A-B-A-B withdrawal single-case experimental design. In the intervention phases, the participants were exposed to biodynamic lighting, while in the placebo phases, the participants were exposed to placebo light. Both light phases came from the same light system. Based on this study protocol, the quantitative effects of biodynamic light related with functional activity did not reach significance. However, the qualitative results of lighting seem promising with a stabilisation of functional activity experienced over time. Future research should examine the effects that light may have on functional activity more in-depth. This study offers recommendations for longitudinal research.

Keywords: dementia; biodynamic lighting; functional disability; community dwelling people; non-pharmacological intervention

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1. Introduction

Functional disability is an important feature of dementia. In order to be able to live at home as long as possible while maintaining a high quality of life, it is necessary that people with dementia maintain their functional status. Functional status consists of everyday activities at home and in the community and meaningful self-care functions that people perform in ordinary, everyday life. It is associated with two major types of abilities. The basic activities of daily living (BADL) are self-maintenance skills, such as eating, bathing, toileting and dressing and are influenced by visuospatial cognitive impairments [1,2]. Visuospatial cognitive function is seeing and processing an observation in space. Instrumental activities of daily living (IADL) are more complex, higher-order tasks that are necessary for independent living, such as the ability to use a telephone, shopping and food preparation [3,4]. Executive dysfunctions crucially influence IADL [5–7]. Executive functioning is a number of cognitive high-level processes that orchestrate complex, goal-directed activities [6,8].

Declines in functional status have been found to be significantly associated with placement in long-term care facilities [4,9]. BADLs tend to be preserved in early-stage Alzheimer's disease, with links to motor rather than cognitive difficulties, while IADLs are

vulnerable to the effects of early Alzheimer's disease, with evidence for a direct link with cognitive status [6,10,11]. Early in the dementia process, the loss of the ability to function adequately may cause the patient to feel useless, dependent, depressed, lower their self-esteem and be burdensome [4,12]. In the later stages of dementia, patients may become largely oblivious to their surroundings and almost totally dependent on caregivers [4]. This is why impairments in ADL are important factors associated with caregivers' burden and quality of life [13–15], especially when caregivers experience behavioural disruptions during their assistance with ADL [16]. It is not surprising that the informal caregivers see external ADL-care as the most important factor in allowing the person with dementia to live at home for as long as possible [17].

In general, clinical practice guidelines on the management of dementia recommend starting with non-pharmacological interventions [18]. There is still no clear evidence that non-pharmacological interventions (e.g., white noise, reminiscence therapy, music therapy, physical exercise) are clinically effective for improving or postponing a decline in ADL [19–22].

Okabe et al. [23] found a significant interaction between circadian rhythm disturbances, cognition and BADL. A non-pharmacologic intervention that could positively influence the circadian rhythm in people with dementia is light therapy (e.g., [24–29]). Through intrinsically photosensitive retinal ganglion cells (ipRGCs) in the retina, light therapy can affect the circadian rhythm situated in the suprachiasmatic nucleus (SCN). In this way, light induces acute alerting and activating effects throughout the 24-h day. In recent decades, several researchers have investigated the possible effect of light on sleep, cognition, mood and behaviour. In a systematic review, Mitoloa and colleagues [30] suggest that the effects of light treatment on people with Alzheimer's disease in general trend toward a positive effect on sleep, cognition and mood. Similar results were found in a recent review based on 36 articles among older people with cognitive impairment on sleep, mood and behaviour. A limited effect was found on cognition, functional status and quality of life [31]. Regarding the efficacy of light interventions among older people with cognitive impairment, bright white light, between 2500 and 10,000 lux in the morning, for 30 min to two hours over two to four weeks seems most beneficial.

Evidence about the positive effect of light therapy and ADL came from a systematic review performed by Forbes et al. [32]. They suggest that bright-light therapy has beneficial effects on ADLs. For example, Riemersma-van der Lek et al. [25] found that light treatment ($\pm$1000 lux) attenuated the gradual increase in functional limitations (ADL) by 53%. Videnovic et al. [33] report (potential) benefits of light therapy on ADL in patients with Parkinson's disease.

However, most research is done with bright light and in a semi-controlled setting (intramural). Due to progressive age-related impairments in the eye and brain of older people, the effectiveness of increased indoor light intensity is insufficient. To have an effect on the SCN, it is suggested that the intensity of light needs to be $\pm$1000 lux [25,34]. Visual acuity and colour contrast naturally diminish with age, but dementia often has major effects on the visual processing systems, which impact the quality of life [35]. In order to draw benefits from light therapy, while taking into account visual limitations, it is important to consider: (1) making use of daylight, (2) orienting on daylight quality (intensity and spectral composition) using spectral weighting functions and dynamic systems and (3) using time-of-day dependent modifications in light quality for maximum wellbeing [35]. A possible intervention that takes these considerations into account is biodynamic lighting (BDL), in which light intensity and colour vary during the day and resemble the intensity and colour of natural daylight. To our knowledge, there is no research yet on the effects of (BDL) on ADL in people with dementia in the home situation. There is a great variety among people with dementia in (ADL) problems, home situation, the amount of time spent indoors and type of dementia. This makes it likely that some will benefit more than others from a treatment or intervention. Studying small subgroups or individual cases is the best way to tease out the details of how to administer the treatment in different circumstances.

Thereby, a field study in the homes of people with dementia is complicated by the fact that the environment is not controlled and is very heterogeneous [36]. With a single case experimental design (SCED), we investigate the effects of BDL in varying circumstances and conditions. The aim of this study is the exploration of the possible influence of BDL on ADL in people with dementia living at home. It was hypothesised that exposure to biodynamic lighting during the day will have a positive effect on ADL.

2. Materials and Methods

2.1. 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 placebo light from the light system, and an intervention condition with two phases (B1 and B2), with BDL from the same light system. For more details about the light, see the 'Intervention' section.

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 [37]. The literature shows it takes about two weeks to adjust the biological clock in people with dementia [38]. 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 programme provided by the Social Psychology Network (http://randomizer.org, accessed on 20 July 2021) [39].

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). The Katz-ADL and Lawton IADL were taken for a baseline level of ADL (see the 'Measures and Materials' section for more information about the different instruments). 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 Programme' (PPP) on their hand-held device or computer and received questions at predetermined times about ADL 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 Katz-ADL and Lawton IADL and switch the light systems to the other light.

A schematic representation of the research design can be found in Figure 1.

2.2. Participants

The participants were recruited from dementia networks of Mental Healthcare (GGzE) in Eindhoven, the Netherlands, between November 2018 and July 2019. Potential participants were made aware of the possibility of participating in this study by their personal GGzE care professionals. They either contacted the researcher themselves if they wanted to participate, or their care professional contacted the researcher. If the potential participants had shown interest, they were invited by the investigator of this study. She provided them with both written and oral information about the study aim, risks, benefits, privacy and rights of participants. If they still wanted to participate one week after the first contact, a home visit meeting took place between the participants and the investigator. Instructions were provided, questions could be asked, informed consent was signed and baseline measurements were taken.

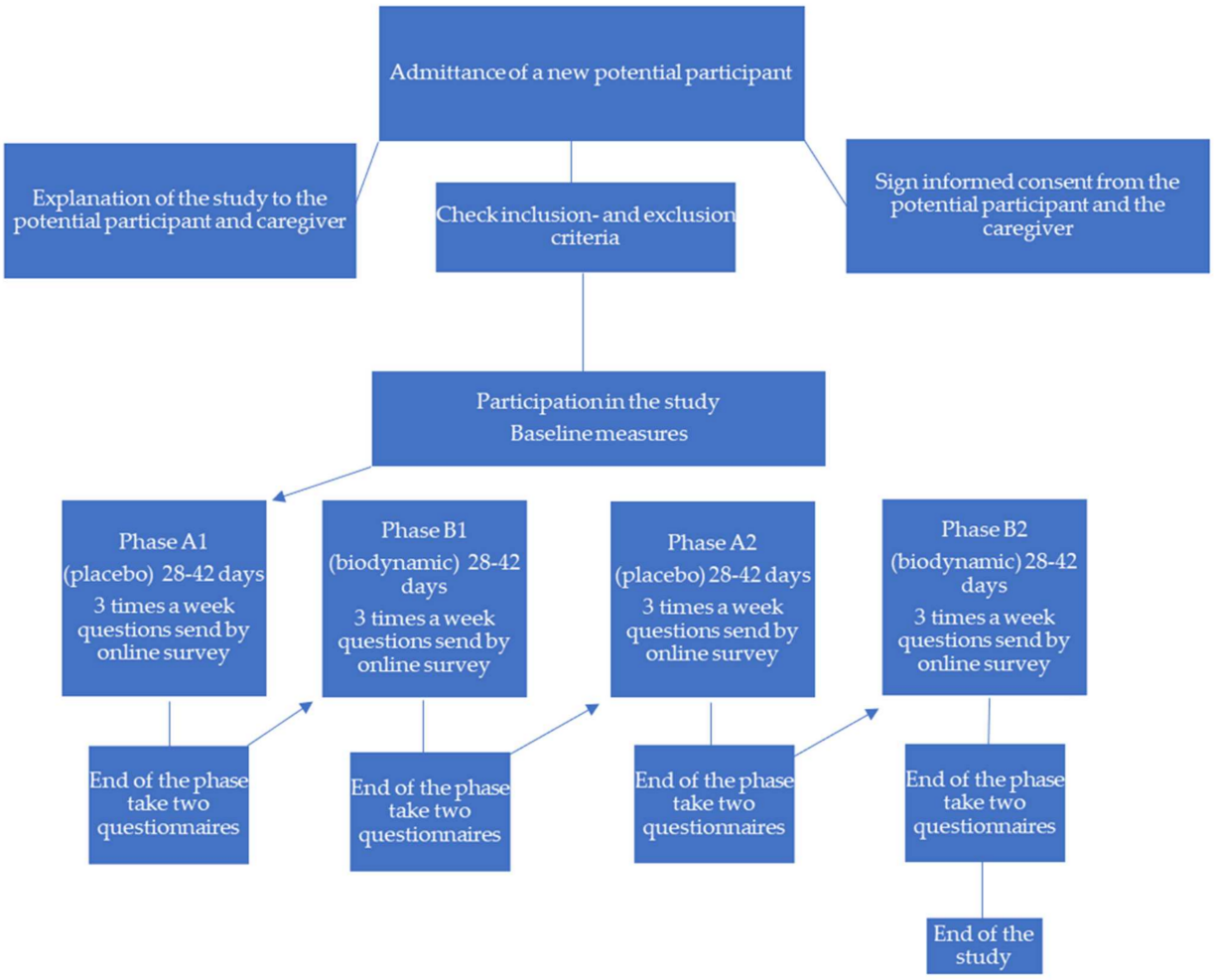

Figure 1. Schematic representation of the research design.

A total of four participants with a diagnosis of dementia were recruited. Three of them were included in the study based on the criteria below, and one participant was excluded because criteria '(iv)' and '(v)' were not met.

In order to be eligible to participate in this study, a person with dementia had to meet all of the following inclusion criteria:

(i) Diagnosed with any type of dementia; in terms of DSM-5 [40] neurocognitive disorder
(ii) Age > 65 years
(iii) Living at home with an informal caregiver
(iv) A score of 1 or higher on a minimum of 3 items of the Katz Index ('limited help needed')
(v) A score of 1 or higher on a minimum of 3 items of the Lawton IADL ('limited help needed')

Exclusion criteria for this study were:

(vi) Ocular/visual problems, e.g., ophthalmic abnormality that greatly impedes light perception, e.g., dense bilateral cataracts
(vii) Pre-existing (severe) psychiatric problems (e.g., bipolar disorder, psychosis)
(viii) Incapacitated according to an objective expert
(ix) Bedridden
(x) Palliative treatment or terminally ill

The main characteristics of each of the three participants (persons with dementia) are listed in Table 1.

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 the 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 (MMSE) Scores (impairment)	19/30 (moderate)	19/30 (moderate)	20/30 (moderate)
ADL problems at start	Dressing (including preparations for dressing) Eating (including preparations for eating) Starting activities Perform activities	Washing/showering Dressing Cooking/ preparing food Medication intake Household	Washing/showering Dressing Eating Medication intake Visiting toilet

2.3. 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.

2.4. Measures and Materials

The Mini-Mental State Examination (MMSE) is an instrument used for the screening of cognitive impairment in the elderly and includes 11 questions. The test evaluates the cognitive functions: attention and orientation, memory, registration, calculation, language and praxis. A low score on the MMSE corresponds to low cognitive functioning [41]. The MMSE was only taken at baseline to map the severity of the dementia.

The Katz-Index of Independence in Activities of Daily Living (Katz-ADL) was developed to study the results of treatment and prognosis in the elderly and chronically ill [42]. Grades of the index summarise overall performance in six domains: bathing, dressing, toilet visits, transferring, continence and feeding. Each domain has four answer options, from complete independence to complete dependence. The Katz-ADL is a useful survey instrument to study a prognosis and the effects of treatments and serves as an objective guide in clinical practices, teaching devices and to gain more knowledge about the ageing process [42]. The Katz is a one-dimensional instrument that can be used to retrospectively

assess ADL by informants, with construct validity and reliability, despite the presence of cognitive decline [43]. The Katz-ADL has a good internal consistency (Cronbach's alphas: 0.84–0.94) for elderly and strong associations with related outcomes: rank correlations 0.64 for long-term limitations in mobility and −0.60 for physical functioning [44].

The Lawton IADL is an instrument to assess independent living skills [45]. These skills are considered more complex than the basic activities of daily living as measured by the Katz-ADL. This instrument is most useful for identifying how a person is functioning at the present time and for identifying improvement or deterioration over time. This assessment instrument is widely used both in research and clinical practice [46]. The Lawton IADL has eight questions with four to six answer options. The domains are meal preparation, using a phone, shopping, housekeeping, financial management, medication management, laundry and transport. The validity and reliability were described as good (inter-rater reliability: $r = 0.85$ and test-retest reliability: $r = 0.93$–0.96 [46].

Positive Perception Programme (PPP) is an online survey consisting of two parts and is used to subjectively measure the received light during the day (part one) and daily ADL outcomes, such as dressing, washing, preparing food and medication intake (part two). In the first part of the survey, 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 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 ADL. For example, 'How much help did your partner get when dressing up (including preparatory work) in the last 2–3 days?' or 'How much help did your partner get when taking medication?'. There is a maximum of six answer categories to answer these questions. Answer category 0 is '0% of the time (completely independent)', 1 is '25% of the time (a little help, most of the task he/she can do himself/herself)', 2 is '50% of the time (he/she can perform as much as he/she cannot do himself/herself)', 3 is '75% of the time (he/she needs help with more than half of the task)', 4 is '90% of the time (almost completely dependent on help)' and 5 is '100% of the time (completely dependent)'.

This online survey was sent to the informal caregiver by the PPP programme (www.ppp-zorg.nl, accessed on 20 July 2021) [47] three times a week. The informal caregiver rated all PPP questions about their loved ones.

2.5. Intervention

The Biodynamic Light System Sparckel, types 'Bright Brenda' and 'Jolly James' (Figure 2a,b), are BDL systems that can be used in a home situation and have been developed after extensive research in a co-production with lighting specialists and end-users [24]. The Bright Brenda and the Jolly James have the same optical characteristics.

Figure 2. (**a**) The Sparckel, type Bright Brenda; (**b**) The Sparckel, type Jolly James.

The intervention in this study is BDL. A fixed day curve programme 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) [24]. 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. The varying colour temperature during the day of the biodynamic lighting lamp is shown in Figure 3 [24], and spectrum analyses are shown in Figure 4a,b. Other important data from the measurement report [48] are shown in Table 2 [24].

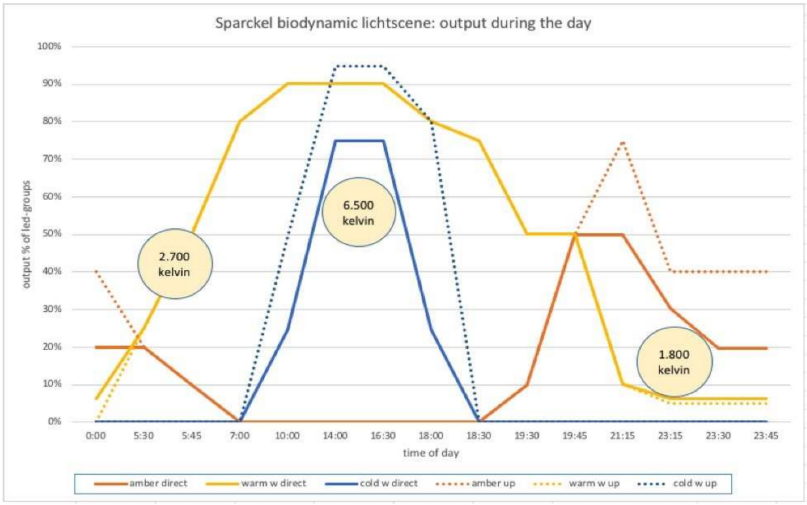

Figure 3. Biodynamic colour temperatures of the Sparckel during a day.

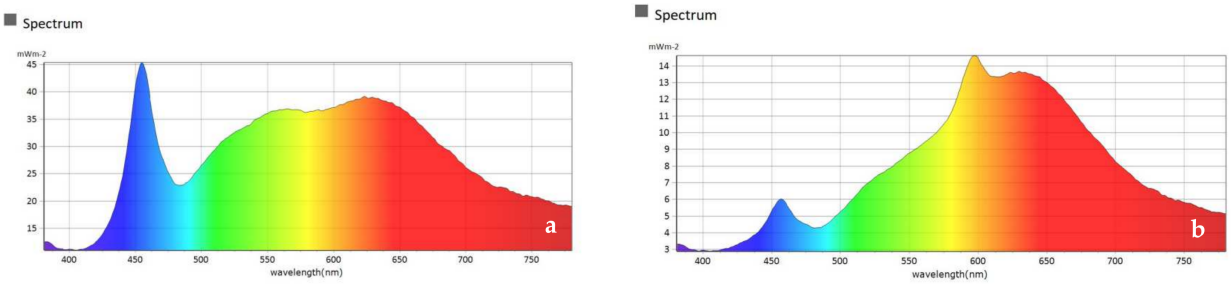

Figure 4. (**a**) Spectrum analysis of BDL; (**b**) Spectrum analysis of placebo light.

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

Parameter	Lamp Measurement	Remark
Colour temperature	4847 K	Direct light
	4750 K	Indirect light
Light intensity	1984.2 Cd	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	6818 lm	1 m distance
Blue light hazard risk	Group 0	No risk

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.

2.6. Data Analysis

This study aimed to explore whether participants improved in their ADL in the intervention condition (BDL) compared to in the placebo condition (placebo light). Data were collected from a minimum of 12 time points to a maximum of 18 time points per phase.

Randomisation tests (RTs) were used for analysing the data obtained from PPP and for analysing whether the amount of light received in the intervention phases differed from the amount of light in the placebo phases. A separate RT was performed for each participant. RTs are nonparametric statistical tests that obtain their validity by computationally mimicking the random assignment procedure that was used in the design phase of a study. Because RTs do not rely on a random sampling assumption, they can provide a better alternative than parametric statistical tests for analysing data from single-case designs [49].

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) [50], 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 [51].

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

2.7. Institutional Review Board Statement

The study was carried out in compliance with the latest version (2013) of the Declaration of Helsinki and approved by the Institutional Review Board of the mental health care institute Eindhoven on 25 October 2018 (reference number IMBB/2018025). All study participants and their informal caregivers gave written informed consent prior to participation.

3. Results

Data were collected between December 2018 and October 2019. All three included participants completed all four phases of the study.

The main characteristics of each participant at baseline (gender, age, type of dementia, education, former work, maternal status/living situation, informal caregiver) are illustrated in Table 1, as well as their cognitive status (MMSE), type of ADL problems and normal light level at baseline without light system. We collected 60 data points for participant one, with a response rate of 98.3%. For participants two and three, 66 and 59 data points were collected, respectively, with cohesive response rates of 75.8% and 79.6%. No significant changes in medication were reported for the three participants during the study.

3.1. Number of Light Minutes during the Day

Measurements of light minutes during the day took place with all three participants, during the intervention phases and the placebo phases, in the morning, evening and time spent outdoors.

For each participant, no significant differences in time (minutes) spent around the light system in the morning could be detected between the intervention phases and placebo phases ($p > 0.05$). These results were similar for the time spent around the light system during the evening and the amount of time spent outdoors (Figure 5). Therefore, every participant received an equal number of light minutes during the day in the placebo phase and the intervention phase.

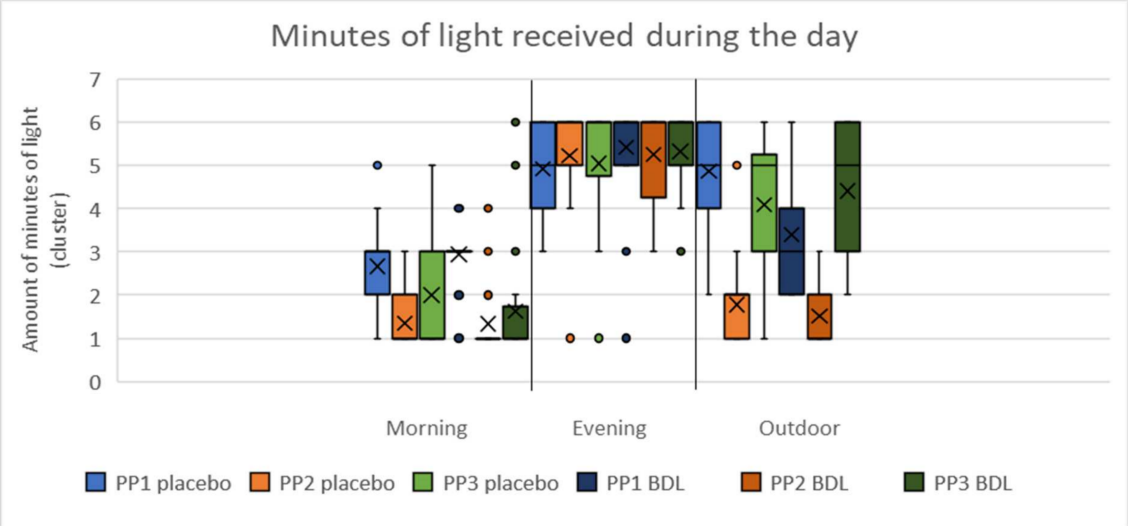

Figure 5. Boxplots of minutes of light received in the morning, evening and outdoor. The median is demonstrated as the 'X' within the boxplot. The length of the boxplot represents the interquartile range, and the boxplot whiskers are 1.5 times the interquartile range. All data points outside the whiskers 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 per day; cluster 5 = 120–150 min light per day; cluster 6 $\geq$ 150 min light per day). Randomisation tests showed no significant difference between morning, evening and outside ($p > 0.05$).

3.2. Amount of Light Minutes during the Morning and Evening

Measurements of light minutes during the morning and evening were taken for all three participants, see Figure 6. The number of minutes of light received in all phases from the light system in the morning (9 a.m.–12 p.m.) was significantly less than the number of minutes of light received from the light system in the evening (7–11 p.m.) for all three participants (Figure 5). Participant 1 had an average of 30–60 min light in the morning, and participants 2 and 3 had an average of 0–30 min light in the morning. In the evening, the average minutes of light from the light system was 120–150 min 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.

3.3. Effect of BDL on ADL (Participant One)

RTs were used to determine whether there was a difference in ADL between the intervention phases and the placebo phases. Figure 7a,b indicates the course of the IADL in participant one over time based on the PPP data collection three times a week. The BADL in participant one (dressing and eating) were reported at baseline but no longer occurred during the study (score 0), and therefore, are not shown in a graph. IADLs in participant one were classified as the ability to start activities and the ability to perform activities. These activities were scored on a range from 0 = completely independent to 5 = completely dependent. Statistical analyses show that none of the IADLs in participant one were significantly lower in the intervention phase with BDL compared to the placebo phase (starting activities $p = 0.65$; perform activities $p = 0.20$). 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.

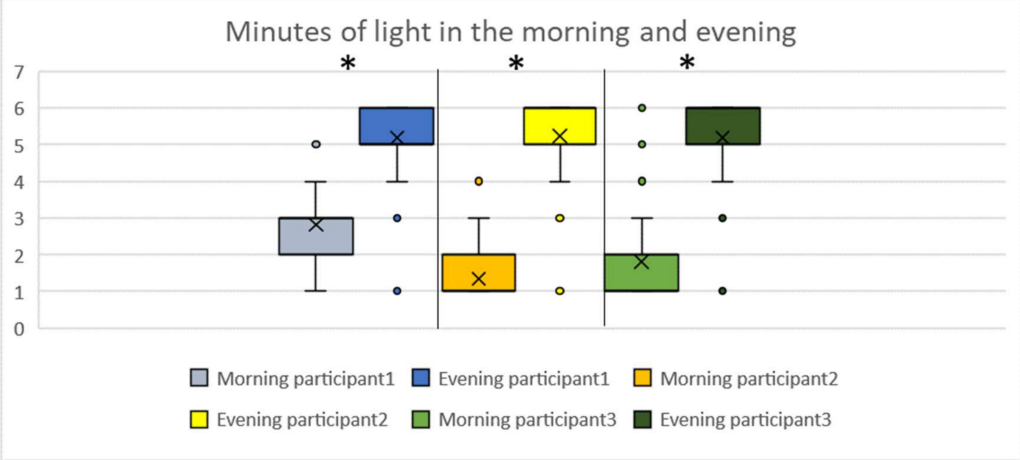

Figure 6. Boxplot of minutes of light received in the morning and evening per participant. The median is demonstrated as the 'X' within the boxplot. The length of the boxplot represents the interquartile range, and the boxplot whiskers are 1.5 times the interquartile range. All data points outside the 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 $\geq$ 150 min light per day). * = Wilcoxon Signed ranks test significant difference between morning and evening ($p < 0.001$).

3.4. ADL Course over Time (Participant One)

The course of BADL and IADL, respectively, in participant one is seen in Figure 7c,d, based on the results of the Katz-ADL and Lawton IADL at the end of each phase. ADL scores that were not changed over time (transferring, toileting, laundry, transportation, medications, finances, use telephone, shopping, food preparation) are not shown in the graphs. Katz-ADL scores range from 0 (completely independent) to 3 (completely dependent). On the Lawton IADL, each item has a different range in scores, with scores in a range from 0 to 5, depending on the item. Score 0 means 'is able to perform this daily activity adequately', with higher scores showing more problems in IADL. Some activities are not applicable because the activity in question is never done, not possible or done less than once a month; they are, therefore, denoted as N/A in the graphs. Visual analyses were performed, and no statistical analysis was performed because of the few data points. The BADL in participant one were improving over time and completely independent of all BADL at the end of the study. The IADL in participant one were stable over time.

3.5. Effect of BDL on ADL (Participant Two)

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 in a country with the same climate as in her home environment).

Moreover, for participant two, it was necessary to determine whether there was a difference in ADL between the intervention phases and the placebo phases, due to BDL. Figure 8a–e shows the course of ADL over time per phase. ADL in participant two were classified as washing and dressing (BADL) and food preparation, medication intake and housekeeping (IADL). Statistical analyses showed that none of the ADL in participant two were significantly decreased by BDL (washing $p = 0.76$, dressing $p = 0.93$, food preparation $p = 0.96$, medication intake $p = 0.72$, housekeeping $p = 0.83$).

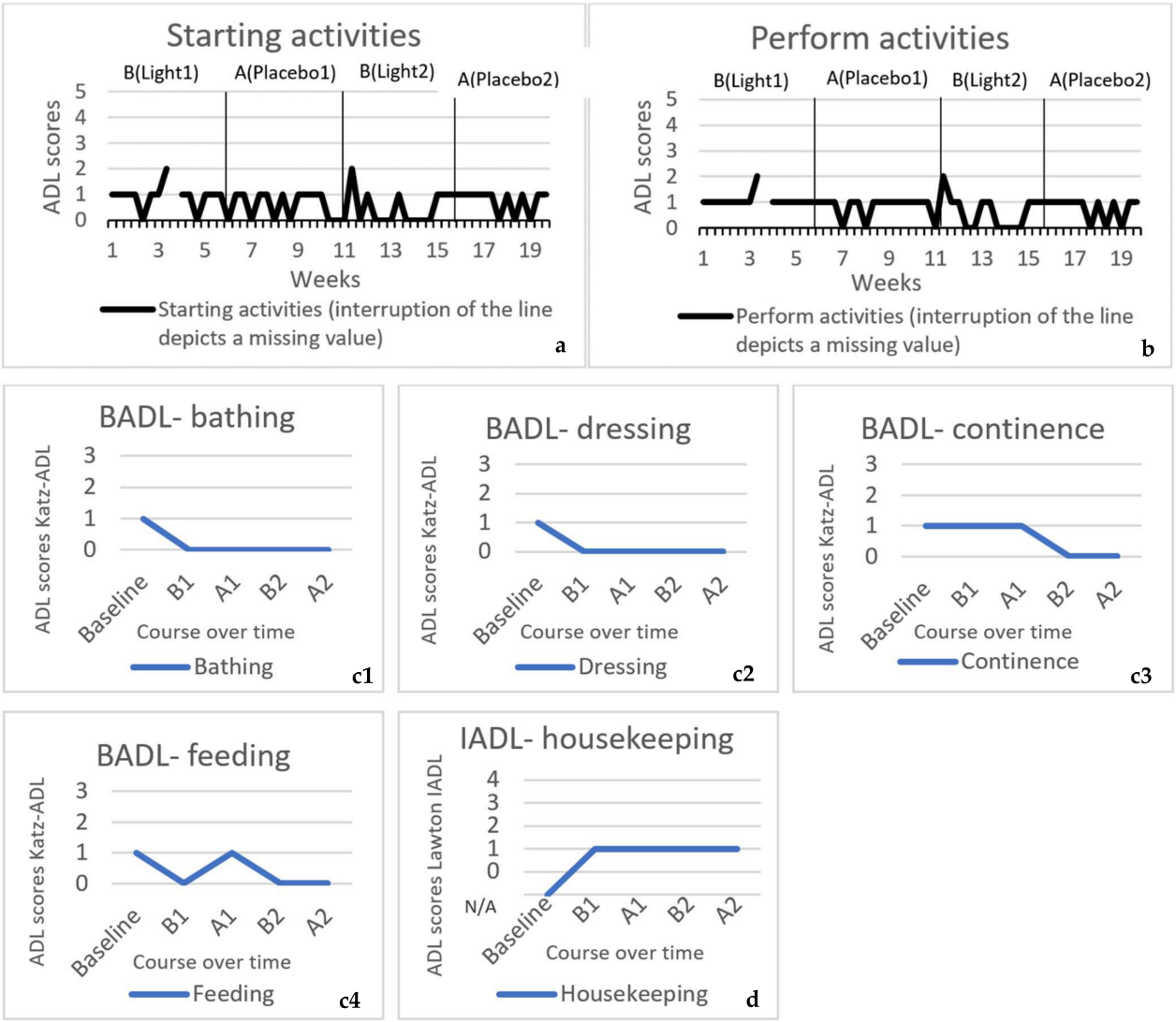

Figure 7. (**a**) Scores starting activities; (**b**) Scores perform activities; (**c1–c4**) Scores Katz-ADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two; (**d**) Scores Lawton IADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two.

3.6. ADL Course over Time (Participant Two)

For participant two, the course of BADL and IADL, respectively, measured with the Katz-ADL and Lawton IADL, is shown in Figure 8f,g. They showed a varying course in ADL, with relatively stable scores in bathing, continence and feeding and a slight increase in dressing, toileting and transferring problems. IADL scores showed a more stable pattern over time, but there is some difference in dependence over time (e.g., shopping). An IADL score that was completely stable over time (housekeeping) is not shown in the graph.

3.7. Effect of BDL on ADL (Participant Three)

In participant three, whether there is a difference in ADL between the intervention phases and the placebo phases due to BDL was also determined. Figure 9a–e shows the course of ADL over time per phase. ADL in participant three were classified as washing, dressing, eating and visiting the toilet (BADL) and medication intake (IADL). Statistical analyses indicated that none of the activities of daily living in participant three were

significantly decreased by biodynamic light: washing $p = 0.59$; dressing $p = 0.33$; eating $p = 0.55$; visiting the toilet $p = 0.49$; medication intake $p = 0.49$.

3.8. ADL Course over Time (Participant Three)

For participant three, the course of ADL, measured with the Katz-ADL and Lawton IADL, is seen in Figure 9f1–f5,g1–g5. ADL scores that were completely stable over time (dressing, using telephone, transportation and medication) are not shown in the graphs. In BADL, there was an erratic course, but none of the BADL increased over time and some even decreased, e.g., feeding was decreased to 'completely independent'. In IADL, a more stable pattern could be seen with even some decrease (for example, food preparation).

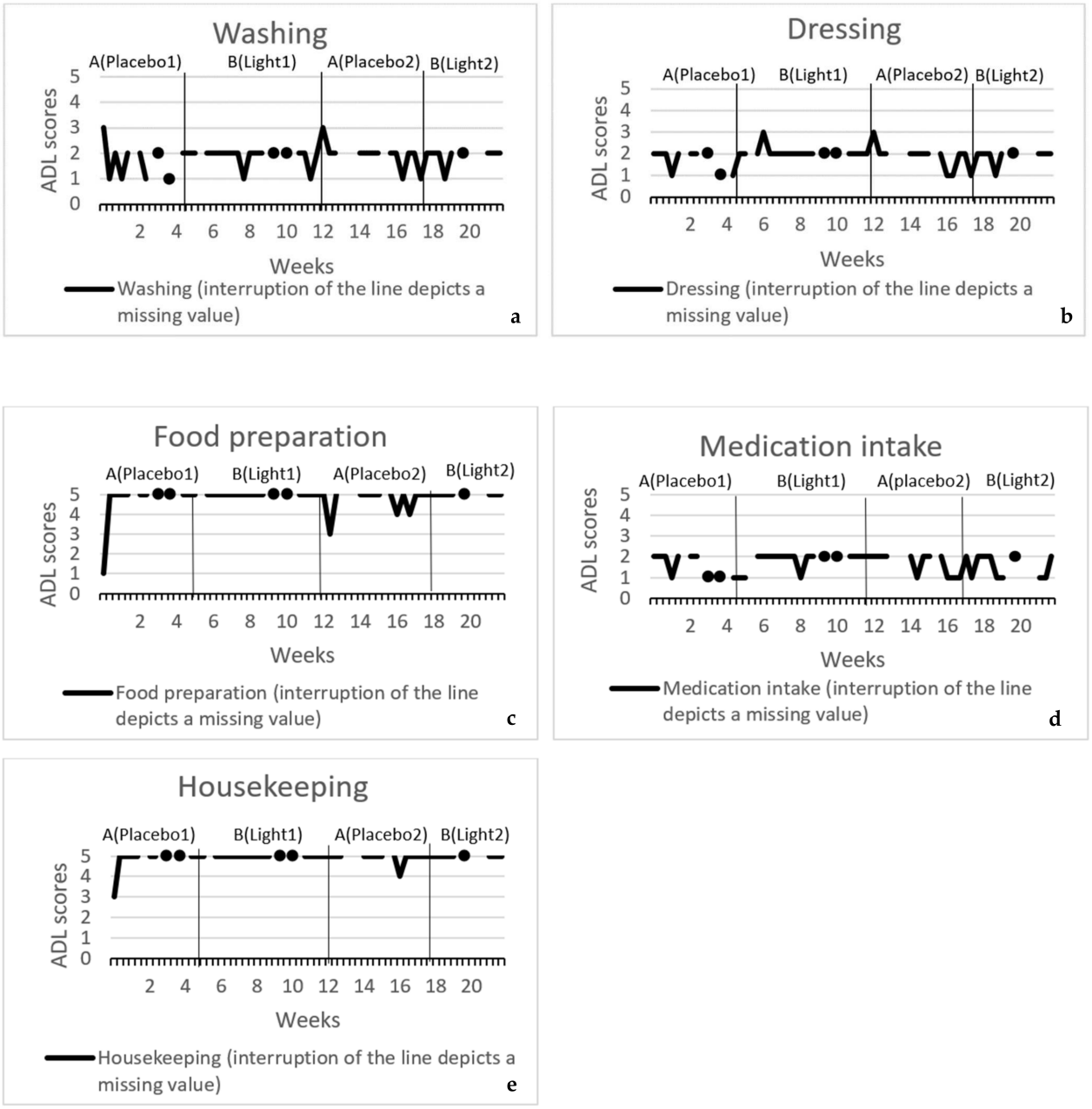

Figure 8. *Cont.*

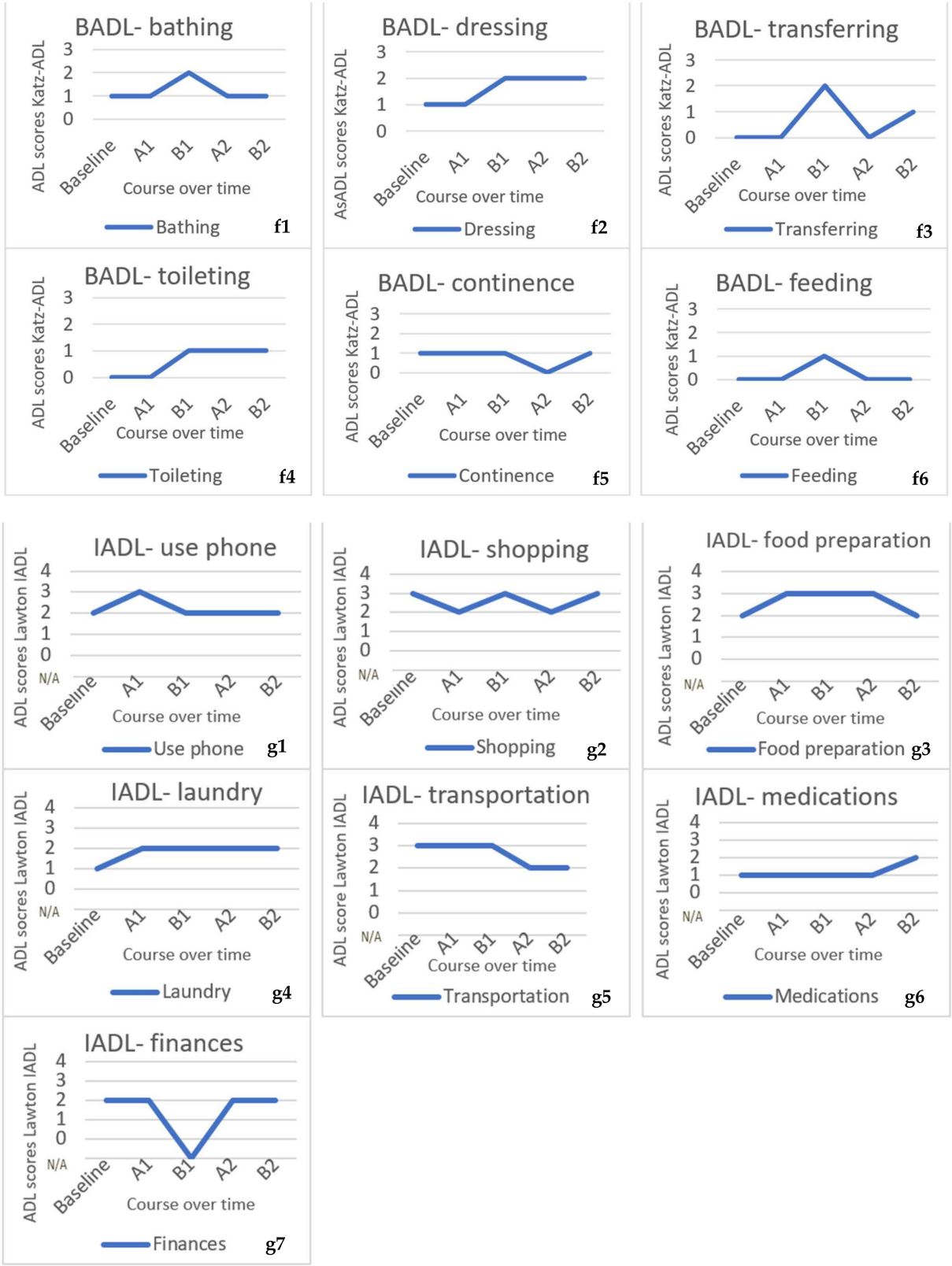

Figure 8. (**a**) Scores washing; (**b**) Scores dressing; (**c**) Scores food preparation; (**d**); Scores medication intake; (**e**) Scores housekeeping; (**f1**–**f6**) Scores Katz-ADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two; (**g1**–**g7**) Scores Lawton IADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two.

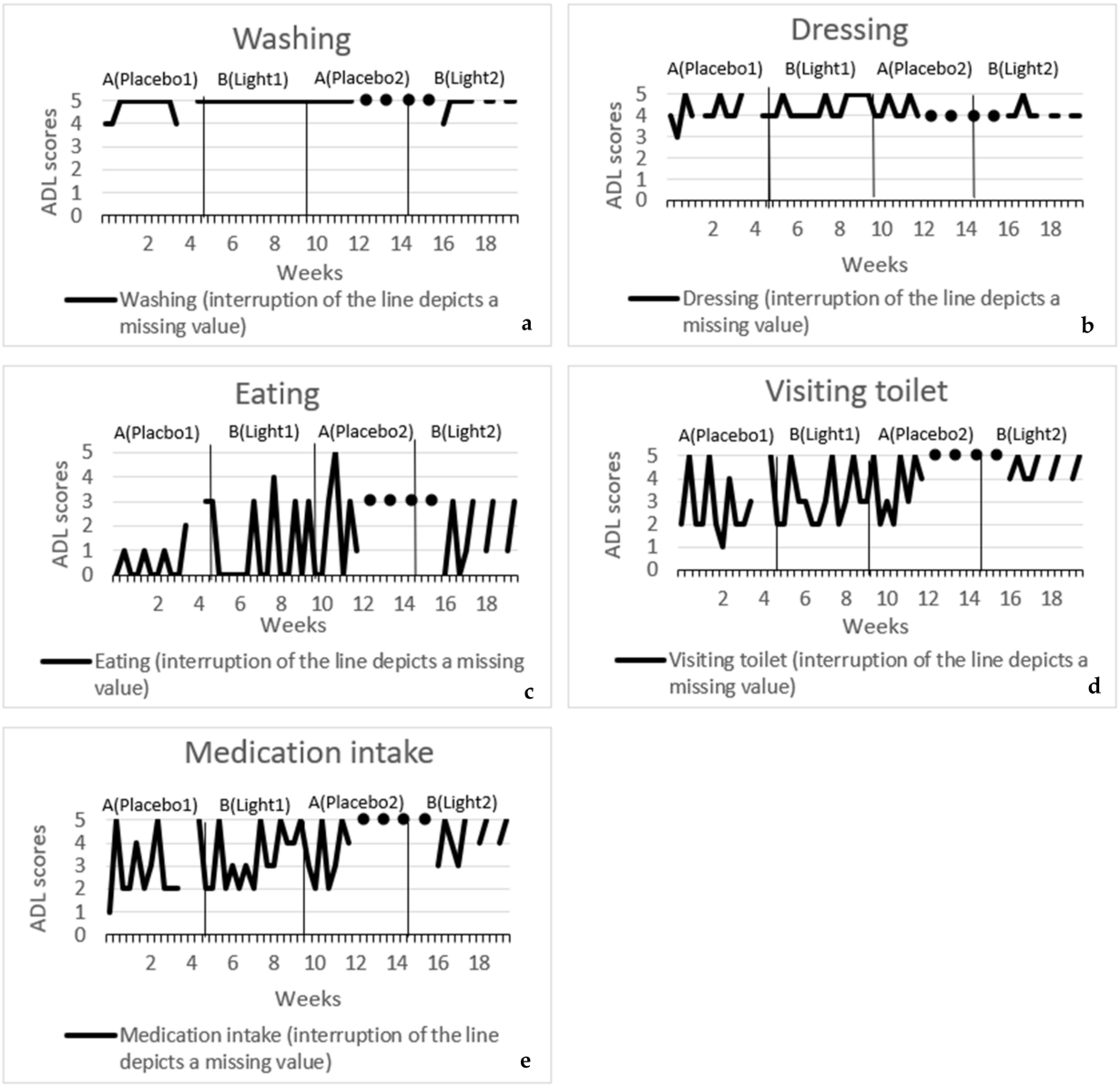

Figure 9. *Cont*.

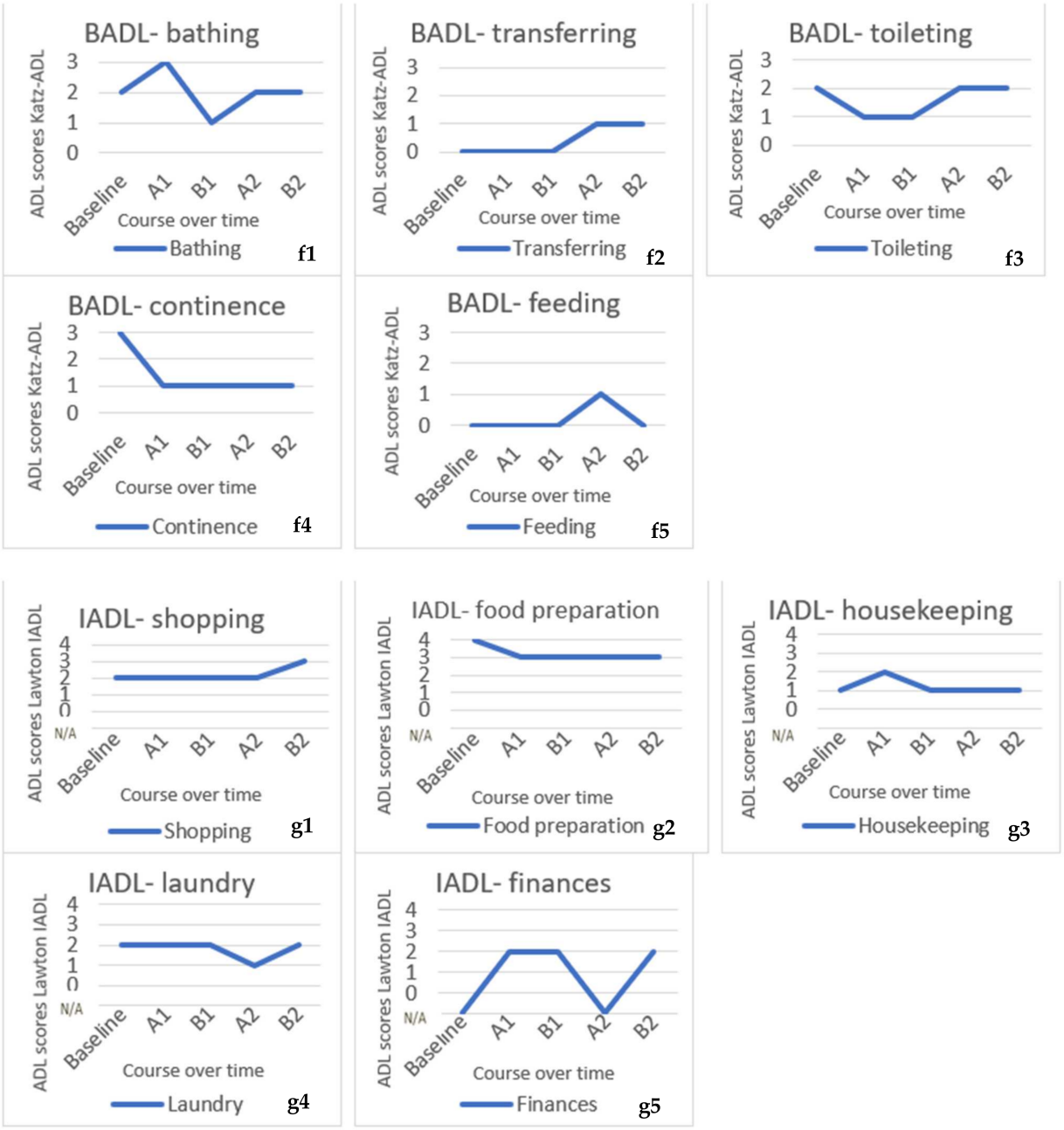

Figure 9. (**a**) Scores washing; (**b**) Scores dressing; (**c**) Scores eating; (**d**) Scores visiting toilet; (**e**) Scores medication intake; (**f1**–**f5**) Scores Katz-ADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two; (**g1**–**g5**) Scores Lawton IADL; Baseline = before start of the first phase; B1 = scores at the end of intervention phase one; A1 = scores at the end of placebo phase one; B2 = scores at the end of intervention phase two; A2 = scores at the end of placebo phase two.

4. Discussion

The aim of this longitudinal SCED study of three participants was to explore the possible influence of BDL on ADL for community-dwelling people with dementia and their informal caregivers.

A study by Riemersma-van der Lek et al. [25] found positive effects of light on ADL in people with dementia in a group-care facility. We hypothesised that exposure to BDL could reduce ADL problems in community-dwelling people with dementia. This study

found no statistically significant differences between BDL and placebo light with respect to ADL problems.

However, other interesting results were found in this longitudinal SCED study. For example, qualitative results showed a stabilisation of ADL over a 5.5-month period with two participants. Because of the neurodegenerative nature of dementia, an increase in problems in ADL is expected without intervention, especially within six months [52]. Therefore, we hypothesised that the light protocol used in this study seems to be helpful to stabilise ADL performances, such as starting and performing activities, housekeeping, bathing and dressing for participant one and washing, dressing, medication intake, food preparation and housekeeping for participant two.

Whereas participants one and two experienced more IADL problems, participant three experienced more BADL problems. Particularly in the last two phases, a deterioration in functioning can be seen for participant three in eating, toileting and medication intake. The deterioration in functioning is not reflected in the Katz and IADL, probably due to the fact the questionnaires are less specific and are administered only once per phase. Therefore, it is more useful to obtain a snapshot of the situation at that moment. From the literature, performance in toileting, transportation and feeding are intact in nearly all patients with mild dementia, with some deterioration reported for the later stages [53]. Giebel et al. [54] stated that bathing and dressing become more impaired with dementia progression. It could be that dementia is in a more severe stage in participant three as compared to the other two participants. For participant three, the course of ADL over a 5.5-month period is more erratic, which could mean that people earlier in their dementia process could have more benefits from light intervention compared to people in a more advanced stage.

Earlier research in people with dementia or Parkinson's disease found a positive relation between bright light and ADL [25,33]. Both studies used bright light with >1000 lux. In our study, there seems to be a trend that low-intensity light (~200 lux) and/or amber/red light could stabilise ADL decrease. Future research is necessary to investigate this finding more thoroughly. Another interesting finding is that our participants received significantly more light in the evening when they were exposed to amber light (in the intervention phases) and low-intensity light (in the placebo phases). Preto and Gomes [55] stated in their review about lighting in the workplace that lighting levels at workplaces for human biological stimulation should be between 500 and 1000 lux. However, other research found evidence that a lower amount of lux (90–180 lux) can have an impact on alertness [56,57]. Therefore, it could be that the placebo light of ~200 lux used in this study may already trigger some biological changes. Further research is needed to identify the amount and type of light that is needed to stimulate ADL performances. Another possible explanation of the stabilisation in ADL can be the fact that the placebo light and the amber/red light provide more light in the home situation compared to baseline. The visual effects of the light can improve vision and will make it easier to perform activities. The advantage of BDL, which was a deliberate decision in this research, is that this kind of light is suitable for daily use (in the morning, afternoon, evening) and seems not to interfere with the daily activities of people with dementia living at home.

The SCN is the principal circadian pacemaker in the mammalian brain, and, as such, it generates circadian rhythms in rest and activity, core body temperature, neuroendocrine function, autonomic function, memory and psychomotor performance, and a host of other behavioural and physiological processes [58]. ADL has an interactive effect on sleep with dementia [59]. Poor sleep at night can lead to further declines in activity levels or behavioural alterations during the day, potentially leading to an inability to perform basic daytime actions in some patients [23,60]. Thereby, physical inactivity can accelerate the progression of ADL disability [22,61], so it is important that the activity rhythm is maintained. The supplementation of light as the primary stimuli acting on the SCN may have improved its abilities to synchronise rhythms in, for example, hormones, metabolism and peripheral oscillators, which concertedly contribute to an individual's general functioning [25]. Although our study lacks evidence for a direct relation between

BDL and ADL performance, it is hypothesised that the influence of light (~200 lux) could stimulate the SCN and caused the stabilisation in ADL problems found in this study.

The guideline with evidence for pharmacological treatment of dementia [62] states that there are some statistically significant improvements with medication. However, drugs do not stop the progression of the disease and do have significant side effects. The advantage of the light used in this study is that there are no harmful side effects [63] when used properly and is easily implemented for a home situation.

Another interesting finding is that, for example, both participants one and three rated housekeeping and finances as 'not applicable' at baseline, but later in time, they started performing these activities. Therefore, it could be that a (small) increase in ADL problems based on the visual analysis can be explained by the fact they carry out more ADL activities. When people start to perform activities that they are not familiar with, it seems likely that they need (more) support. However, the fact that they perform more ADL activities during this light intervention study is interesting to report.

Some limitations have to be considered. The placebo light used in this study (~200 lux) has a higher amount of lux compared with regular daily light (baseline) the participants are exposed to. Perhaps the illumination as placebo light was too high with the result that it might have nullified positive effects of the intervention [64]. Therefore, a third phase of baseline light should have been taken into account. On the other hand, due to this study design, in some cases, a lower amount of lux instead of the suggested 1000 lux from the literature [25,34] could also have an effect on the stabilisation of ADL problems in people with dementia. Another limitation is that it has not been objectively measured how much light (intensity and colour spectrum) the participants actually received. It was asked in the online surveys how many hours a day they actually received light from the light system (between 9 a.m. and 12 p.m. and between 7 p.m. and 11 p.m.) and how many minutes the participant spent outside. Although statistical analyses indicate that there is no significant difference in time spent around the light system and the time spent outdoors between the two conditions, these data still do not guarantee that people consume less lux in the placebo condition than in the intervention condition because this also depends on the brightness during the day. For future research, it is highly recommended that a lux sensor be installed in the room (or near a person) that continuously measures the amount of lux and colour spectrum of the light, where illuminance and non-visual effect levels should be measured at the eye level. Based on the objective light measurements (86 to 121 lux with regular daily light, ~200 lux with placebo lighting and up to 1100 lux with BDL), an assumption was made that during the intervention condition (with BDL), more lux was offered compared to the normal or placebo situation. In this study, the participants were not living in a controlled environment and could not be restricted to staying at home all day. It could be that the participants received more lux (from natural sun-light) during the moments in which they believed they were receiving less light. It could be that these artifacts cloud the relation between BDL and ADL performances.

In this study, SCED was used, allowing for more individualised testing and experimental results. Inherently, there is no group of participants by which interferences were extrapolated at the level of individuals. Rather, treatment responses were evaluated at the level of the individual. Although this means external validity is low (i.e., conclusions regarding the whole target population cannot be drawn), outcomes of SCEDs can facilitate the design of larger cohort studies or RCTs in the future.

5. Conclusions

This SCED shows no significant improvements in ADL based on the consumption of artificial light (BDL) in community-dwelling people with dementia. However, the light protocol used in this study could stabilise the ADL. Further research is needed to identify the amount and type of light that is needed to stimulate ADL performance.

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Institutional Review Board Statement: The 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 health care professionals. All subjects gave their informed consent for inclusion before they participated in the study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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