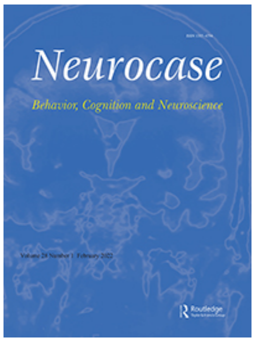

Neurocase

Behavior, Cognition and Neuroscience

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nncs20

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To cite this article: Sterre Smits, Erik Oudman, Mareike Altgassen & Albert Postma (2022) Smartwatch reminders are as effective as verbal reminders in patients with Korsakoff's syndrome: three case studies, Neurocase, 28:1, 48-62, DOI: 10.1080/13554794.2021.2024237

To link to this article: https://doi.org/10.1080/13554794.2021.2024237

Published online: 27 Feb 2022.

NEUROCASE
2022, VOL. 28, NO. 1, 48–62
https://doi.org/10.1080/13554794.2021.2024237

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Smartwatch reminders are as effective as verbal reminders in patients with Korsakoff's syndrome: three case studies

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ABSTRACT
Korsakoff's syndrome (KS) is a neurocognitive disorder caused by severe malnutrition. KS patients typically show severe impairments in prospective memory (PM), thus, have difficulties with remembering to perform delayed intentions. The current study investigated the possible benefits of a smartwatch aid for PM tasks in patients with KS and compared its efficacy with verbal in-person reminders. Three patients participated in the present study and were asked to complete everyday PM tasks. The results of each patient were analyzed as a single-case study. The results highlight the great potential of using smartwatches as external memory aids in KS patients in everyday life.

ARTICLE HISTORY
Received 24 June 2021
Accepted 24 December 2021

KEYWORDS
Korsakoff's syndrome; prospective memory; reminders; smartwatches; case study

Introduction

Korsakoff's syndrome (KS) is a neurocognitive disorder caused by thiamine deficiency (Arts et al., 2017; Johnson & Fox, 2018). This deficiency can result from malnutrition that frequently follows excessive alcohol use and self-neglect. KS is associated with severe cognitive deficits (Scalzo et al., 2015); with episodic memory being heavily affected (Aggleton, 2008; Burgess et al., 2002; Kopelman et al., 2009). The most prominent characteristic of KS patients is impaired anterograde memory; hence, patients are unable to acquire new information (Butters & Cermak, 1974). In addition, retrograde amnesia, disorientation, executive dysfunction, apathy, anxiety, and confabulations are present in KS (Arts et al., 2017; Thomson et al., 2012).

Two of the impaired functions described above are essential for successful prospective memory (PM) performance, namely episodic memory and executive functioning (Gonneaud et al., 2011; Kliegel et al., 2002). PM refers to remembering to perform an intended action at a later event or time. Successful PM is needed to organize your daily routine and to carry out social and work-related demands (Altgassen et al., 2016). PM tasks, such as remembering to send an e-mail at a certain time, include two components: the "what" and the "when" component (Einstein & McDaniel, 1996; Lloyd et al., 2020). The "what" component refers to the content of the intention and mainly relies on episodic memory (Gonneaud et al., 2011). The "when" component refers to remembering to perform the action at the correct time (e.g., remembering to go to a meeting at 2 o' clock) and is mainly supported by executive control processes (Gonneaud et al., 2011; Lloyd et al., 2019). Successful PM is of crucial importance for people's social relationships, performance at work and health (e.g., remembering to take their medication), and is thus critical for being able to live independently.

A growing number of studies have shown that PM is impaired in KS (Lloyd et al., 2020). For instance, Brunfaut et al. (2000) compared PM performance between KS patients and individuals with alcohol use disorder. Participants had to perform an ongoing task (e.g., count the letters of presented words) and a PM task (e.g., remember not to count the letters of animal words but instead to press the red space bar of the keyboard). The results indicated an overall impaired PM performance in individuals with KS as compared to individuals with alcohol use disorder. Interestingly, KS patients performed better on PM tasks when ongoing and PM task required the same cognitive processes (e.g., perceptual ongoing task and perceptual PM task) than when both tasks required different cognitive processes. Altgassen et al. (2016) investigated the impact of executive control demands on PM performance in KS. Specifically, the salience of PM cues was manipulated (using low vs high salient cues) resulting in higher or lower demands on participants' monitoring behavior for the PM cues (McDaniel & Einstein, 2000). Overall KS patients had fewer PM hits than alcoholic controls. Moreover, KS patients' performance on PM was better in the high salience condition compared to the low salience condition. This effect was not seen in alcoholic controls. Consistently, Lloyd et al. (2020) reported that KS patients performed PM tasks less accurately than patients with alcohol use disorder. Furthermore, the authors found that showing an instructional video demonstrating the PM intention improved PM performance and later recall of PM task instructions in KS patients. This result was mainly seen in relatively high-functioning KS patients. Taken together, these findings indicate that KS patients have severe deficits in PM, which may contribute to their everyday difficulties with social and work-related demands.

Given the importance of PM for daily life functioning there is a clear need for designing effective PM tools that may support PM performance in everyday life. External memory aids are

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used widely as an intervention for assisting people with PM impairments (McGoldrick et al., 2019). The aim of this compensatory approach is to bypass the deficit and use the memory aid to solve functional problems. These memory aids, when used correctly, can help the individual to manage their daily life routine despite cognitive impairments. When looking specifically at KS, earlier research indicated that patients diagnosed with KS do benefit from memory aids to improve their autonomy (Rensen et al., 2017). For instance, errorless learning strategies can be used to improve different types of everyday tasks (e.g., daily chores, mobility, housekeeping). Taken together the foregoing strongly suggests that effective PM interventions can help to improve autonomy and thereby increase the feeling of independence and improve quality of life in KS patients (Bonk, 2016; Oudman & Zwart, 2012). Importantly, external memory aids may even reduce the workload of nursing staff in care homes to which KS patients are often admitted. Caring for people with KS may be challenging given KS patients' lack of insight into their deficits that makes them often unwilling to accept care (Gerridzen et al., 2019).

A most effective intervention to improve PM in both patients with cognitive disorders and in healthy individuals is using external memory aids, such as a diary (Cicerone et al., 2005). The first case study in KS to investigate the effectiveness of a memory aid was performed by Davies and Binks (1983). This study used prompt cards and leaflets as external memory aids. The results showed that these aids helped patients to successfully retrieve information important for independence in daily life (Davies & Binks, 1983). Similarly, Morgan et al. (1990) and De Fatima Alves Monteiro et al. (2011) both reported beneficial effects of using assistive technology as an external memory aid. The former observed an attendance rate of more than 80% in KS patients after both verbal directions and digital paging (Morgan et al., 1990). De Fatima Alves Monteiro et al. (2011) incorporated assistive technology into a 25-week neuropsychological rehabilitation training for KS patients during which patients learned to use notes, schedules and a calendar. Overall, results suggested that the assistive technology was helpful within the rehabilitation plan, but, the effectiveness of the memory aid was based on subjective reports rather than objective measures which may reduce the reliability of results.

A more recent case study by Lloyd et al. (2019) investigated the beneficial effect of a smartwatch in a patient with KS. The participant was highly educated, but had to move to a specialized long-term care facility after developing KS. The smartwatch was designed as an external memory aid for PM tasks. This single-case study compared time accuracy and performance of PM tasks within a KS patient across three conditions: a smartwatch, the patient's mobile phone and no external memory aid. The results showed that time accuracy (the "when" component of PM) was significantly better when having a smartwatch as an external memory aid compared to no aid. Interestingly, the phone condition did not differ from the no aid condition. The precision of the PM task (the "what" component of PM), i.e., whether the task was performed correctly or not, was significantly higher when an external memory aid was available. Here, the mobile phone and smartwatch were equally effective as the no aid condition. These findings suggest that a smartwatch could significantly improve PM in this KS patient. However, it is of note that the patient in Lloyd's study was high functioning (PhD degree, IQ>120) and it is unclear if lower functioning KS patients may also benefit from a smartwatch. Moreover, PM tasks comprised rather artificial assignments (e.g., sending a picture of specific objects) that were not of relevance for the patient's everyday life. Importantly, it has been shown that assignments that have personal or social relevance may stimulate PM functioning (McDaniel & Einstein, 2000). If we could show that external aids increase the execution of daily life tasks, this may have significant implications for the development of clinical interventions and patients' autonomy.

Therefore, the present study set out to further investigate the possible beneficial effects of a smartwatch as an external memory aid on everyday PM in KS patients with a broader range of intellectual functioning. A smartwatch condition was compared to the more standard nursing home routine of giving explicit verbal reminders (e.g., by care takers). Our hypothesis was that there would be no significant difference between reminders on the smartwatch and verbal reminders on PM performance in KS patients.

Methods

Participants

Three KS patients participated in this study. All of them met the diagnostic criteria for KS, as stated by Kopelman (2002), and for major neurocognitive disorder due to alcohol, named in the DSM-5 (Nuckols & Nuckols, 2013); other etiologies were excluded.

All three patients had a low "instrumental activities of daily life" (IADL) functioning. The patients were recruited from "Slingedael",a specialized long-term care facility for KS patients in the Netherlands (Table 1). They were selected based on their willingness to participate. The faculty ethics board of Utrecht University approved this study. All participants gave written informed consent before data collection. Each patient was tested individually.

- = Score below the cutoff (<26) indicating mild cognitive impairment (Nasreddine et al., 2005)

Table 1. Demographic characteristics patients.

	PT1	PT2	PT3
Sex	Male	Male	Female
Age	53	56	63
Level of education	4	5	7
MoCA	21*	16*	23*
Year of diagnosis and admission to the KS center	2010	2020	2018
Self reported drinking habits	16 bottles of beer a day (2016–2020)	24 bottles of beer a day (1985–2009)	3 bottles of wine a day (2010–2020)

Level of education based on scale Verhage (1964); low-educational level (1–4), mid-educational level (5) & high-educational level (6–7)

Materials and Procedure

Neuropsychological baseline assessment

When the patients were first registered at the Korsakoff's center Slingedael, they all completed a neuropsychological assessment (Table 2). Patients' test performances were compared with those of people who had an average education level. However, patient 3 is a highly educated woman. This should be taken into account when reviewing the score performances of patient 3. Working memory was measured with the digit span test (DS). Memory was assessed with the visual association test (VAT) and the Rey Auditory Verbal Learning Test. Executive functioning was measured with the Trail Making Test (TMT), the Stroop Color-Word-task and the Behavioral Assessment of the Dysexecutive System (BADS). Additionally, at the beginning of the testing week of the present study, patients completed a cognitive screening test, namely the Montreal Cognitive Assessment (MoCA) (see, Table 1 for results).

PM tasks

The study took place at the Korsakoff's center "Slingedael" in Rotterdam. Each patient underwent both, the smartwatch and verbal reminder condition for five consecutive days. For all participants, the first condition was the smartwatch condition followed by the verbal condition. The smartwatch used in the experiment was the MyWepp Guide pictowatch, developed by Brevidius, to enable people with a cognitive impairment to function as independent as possible. Smartphone, tablets and/ or smartwatches have a choice of agendas, reminders, medication alerts, video communication, combined with all sorts of entertainment, instructions and news/information to help structure their day. These functions are optional and can also be disabled if preferred. In our study, the smartwatch only showed the time and task reminders; no other functions were available to reduce its complexity and to keep cognitive demands to a minimum. At the beginning of each testing day the patient was presented with

Table 2. Neuropsychological assessment.

Construct	PT1 Raw score	Standardized score*	Descriptive labels **	PT2 Raw score	Standardized score*	Descriptive labels **	PT3 Raw score	Standardized score*	Descriptive labels **
Working memory									
DS-Forward	X	T = 52	Average	X	S = 5	Below-average	4	T = 16	Exceptionally low
DS- Backwards	X	T = 60	Average	X	S = 3	Below-average	5	T = 29	Exceptionally low
DS- Corrected	X	X	X	X	S = 4	Exceptionally low		T = 45	Average
Episodic memory									
VAT (long)	3	P = 0	Exceptionally low	8	P = 0	Exceptionally low	19	P = 11	Low-average
Rey Auditory Verbal Learning Test – Encoding	4-5-5-5-5-	T = 27	Exceptionally low	2-3-2-4-6	T = 15	Exceptionally low	5-5-7-8-9	T = 36	Low-average
Free recall	1	T = 21	Exceptionally low	0	T = 14	Exceptionally low	6	T = 37	Low-average
Recognition	1	T = 32	Below-average	6	T = 37	Low-average	30	T = 46	Average
Executive functions									
TMT A	X	P = 66	Average	X	Score unknown	Below-average	53 sec	T = 30	Below average
TMT B	X	P = 58	Average	X	Unable to finish	X	147 sec	T = 24	Exceptionally low
TMT B/A	X	P = 60	Average	X	Unable to finish	X	2.77	T = 31	Below average
Stroop Color-Word test –1	X	T = 52	Average	X	X	X	60 sec	T = 28	Exceptionally low
Stroop Color-Word test –2 Stroop	X	T = 49	Average	X	X	X	93 sec	T = 21	Exceptionally low
Stroop Color-Word test –3	X	T = 37	Average	X	Scores unknown	Average	154 sec	T = 29	Exceptionally low
BADS									
Rule shift cards	X	PS = 1	X	X	X	Unable to finish	1	PS = 3	X
Action program	X	PS = 3	X	X	X	Correctly performed	5	PS = 4	X
Temporal judgment	X	PS = 3	X	X	X	Correctly performed	16	PS = 4	X
Key search	X	PS = 2	X	X	X	Performed incorrectly	0	Ps = 1	X
Zoo map	X	PS = 3	X	X	X	X	11	PS = 1	X
Modified six elements	X	Unable to finish	X	X	X	X	4	PS = 4	X
Total		14.4	Low average					17	Average

*Scores meaning: T= T-scores, S= score, P= percentile

** Descriptive labels are formed from the distribution of standard scores according to the normal distribution and the North American qualitative descriptions (Guilmette et al., 2020).

a list of tasks (see list in appendix 1–6). This list contained a description of the tasks and times they needed to be performed. The patient was asked to perform these specific tasks at a specific time. Importantly, tasks were part of the typical routine of a patient (e.g., set the table at 9 o'clock). Each day the patient had to carry out three tasks, resulting in a total of 15 tasks per condition. Each patient had a different schedule; some had more activities than the other, therefore some of the PM tasks had to be repeated during the week in order to reach 15 PM tasks. In the *smartwatch condition* the watch vibrated, showed a picture of the task and gave a vocal description of what needed to be done at what time (e.g., go to the gym at 11 o' clock). In the *verbal reminder condition*, the researcher would walk up to the patient and give the exact same description as the one given by the smartwatch with no further explanation. In both conditions a reminder was given 15 minutes prior to when the patient was supposed to complete the task, as well as five minutes after the specified time. If the patient did not initiate his/her tasks until at least 15 minutes after the specified time, the researcher would pick up the patient. During both conditions, the patient was monitored whether he/she performed the tasks. In addition, the patient wore the smartwatch in both conditions; however, in the verbal condition it only served as a clock. The dependent variables were: precision of the PM tasks (correct or incorrect) and PM time accuracy (in minutes difference from the assigned time; max 15). If the patient did not perform one of the PM tasks, he/ she would receive a max score of (+) 15 for time accuracy and an "incorrect" for precision. It would be better if the patients got an incomplete instead of a + 15 when they did not perform the PM task, however if we take out these scores there is to little data for an analyses.

Time measurement

We measured the absolute time error. The *absolute* time reveals how many minutes away from the intended time the PM task was performed, ranging from 0 to 15. Moreover, we computed a categorical time error, separating "being on time" from "off time". For the patient to be on time we set a critical range between 0 and 7.5 minutes away from the intended time the PM task was performed. When the patients responded outside this range, they were judged to be "off time" (again making a period of 7.5 minutes). This categorical time score resulted in a binary outcome measure (on time vs off time).

Further assessments

At the end of each testing day the patient was asked in an episodic memory test to freely recall the PM tasks that they performed that day. Furthermore, they were asked to state how they were reminded to do them (i.e., verbally or by the smartwatch), and were requested to put all PM tasks in chronological order. This was done to explore which of the two reminder methods yields stronger retrospective episodic memories. This data can also show whether successful PM performance leads to better episodic memory for the PM action.

Thereafter, the patient was also asked what he/she thought and felt about the way he/she was reminded of the tasks on that specific day. The answer was scaled as positive, negative of neutral. Lastly, at the end of the 2 weeks of testing; the patient had to indicate which kind of reminder he/she preferred.

Data analysis

We employed a within-subject design. For each patient 30 PM tasks were assigned: 15 per condition. The results of each patient were analyzed individually. This was done because of the relatively small amount of data (Dugard et al., 2012). The analysis was carried out using SPSS version 27. The Shapairo–Wilk test indicated that the data was skewed [$p < .01$] and the Breusch-Pagan test showed that there was equal variance across conditions ($p > .0$)

To analyze for possible differences in the absolute across conditions, we used the Mann–Whitney *U*-test, a non-parametric alternative to a one-way ANOVA. The categorical time error (on time or not on time) and the precision of the PM task (correct or incorrect) are a binary outcome measure for which we used the chi-square test of independence.

The episodic memory free recall (correct or incorrect) is also binary outcome measure. For this we used a chi-square of independence. For the episodic memory free recall the patients would receive a score between 0 and 15 per condition (one point per correct answer). A temporal gradient (i.e. PM performance over the days of the week), can be seen in figure 1,2,3 b/c. Patient

Table 3. Descriptive statistics of the absolute and categorical time accuracy off PM tasks per condition

Time accuracy	Condition	Mean (min) Absolut	SD (min) Absolut	Median (min) Absolut	Mean (min) Categorical	SD (min) Categorical	Median (min) Categorical
PT1	Smartwatch	11.0	4.07	12.0	1.40	12.0	6.00
	Verbal	8.47	5.69	10.0	-6.07	8.35	-10.0
PT2	Smartwatch	13.7	3.60	15.0	6.33	13.0	15.0
	Verbal	11.1	5.71	15.0	0.867	12.8	- 2.00
PT3	Smartwatch	7.07	4.95	6.00	-1.20	8.74	- 2.00
	Verbal	7.27	4.59	7.00	-1.93	8.58	- 3.00

preference was measured by a visual inspection of the data. We reported the responses off the patients to the watch and the verbal reminders and their overall preference (appendix 2). The source memory, temporal order memory and the possible relationship between memory for the PM task (i.e., episodic memory) and the correct PM performance (on time and correct) were also measured by a visual inspection of the data. If the patient could correctly state how he/she was reminded to the smartwatch (source memory) he/she would get a score of 1. That leaves the patients with a total score (per condition) that varies between 0 and 5. If the patient could correctly state the chronological order (temporal memory) of the PM tasks performed that they he/she would get a score of 3, 1

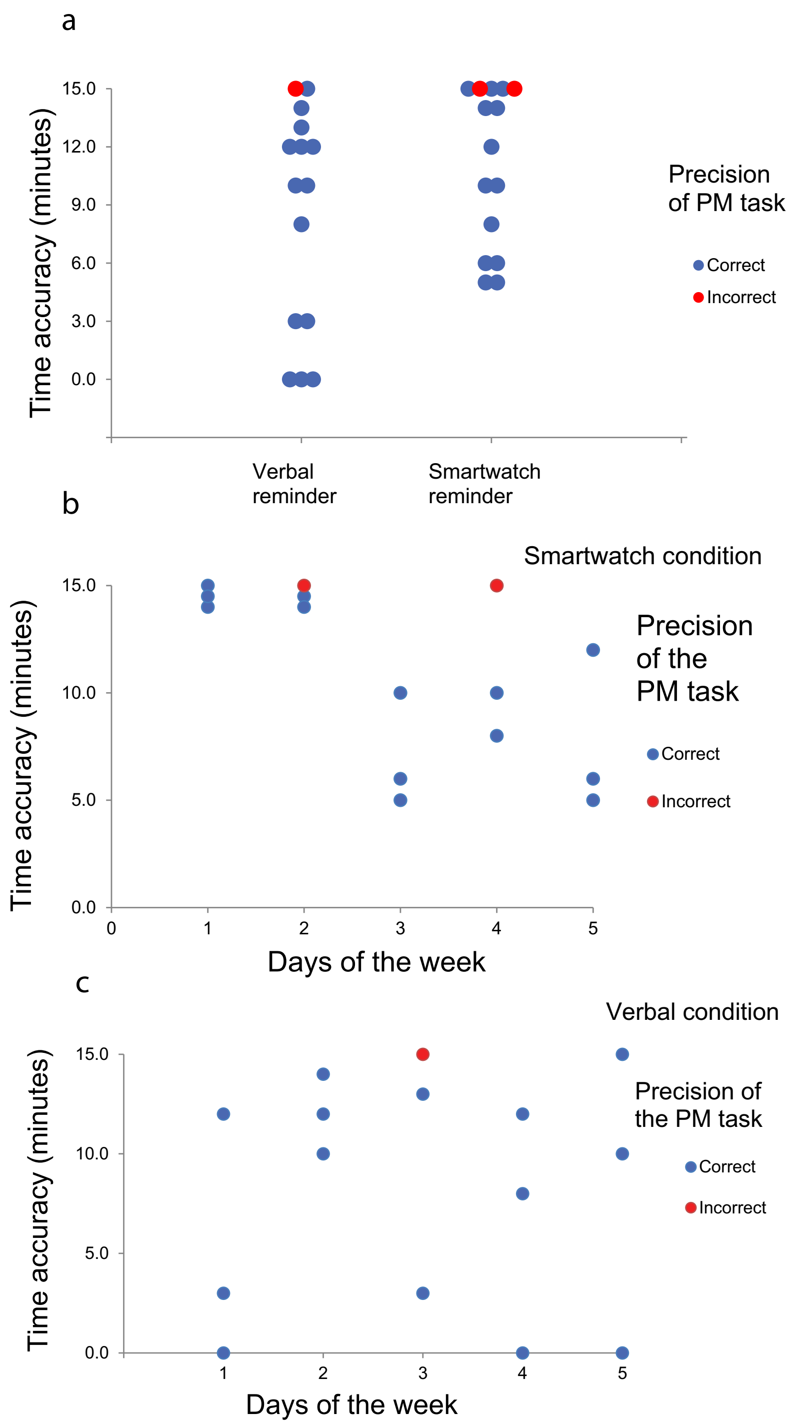

Figure 1. (A) Results patient 1 absolute time error (absolute difference in minutes between the time at which a prospective memory assignment was carried out and the time it was intended. Data points show the assignments during a week in which either verbal reminders were given or smart watch reminders. When task/ action carried out did not correspond to what was intended it was scored as incorrect).(B) Performance over time patient 1 – smartwatch condition.(C) Performance over time patient 1 – verbal condition.

point for each correctly placed PM task. This leaves the patient with a total score (per condition) that varies between 0 and 15.

Three observations during the smartwatch condition were excluded during the testing period of the first patient. One observation was excluded due to a technical issue on the smartwatch that prevented the patient from seeing which task he needed to perform and two due to the fact that the patient took off the smartwatch and left it in his room (please also see the discussion section). Because of the small amount of data available, this patient had one extra testing day in order to obtain 15 valid data points.

Results

Case studies

Results patient 1

Time accuracy on PM tasks.

Absolute time error. The Mann–Whitney *U*-test indicated that there was no significant difference in time accuracy on PM tasks between the smartwatch condition (*Mean Rank* = 17.60, $n = 15$) and the verbal condition (*Mean Rank* = 13.40, $n = 15$), $U = 81.000$, $z = -1.320$ (corrected for ties), $p = .187$ (Table 3 & Figure 1a).

Categorical time error. A Pearson's chi-square test of contingencies (with $\alpha = .05$) was used to evaluate whether there was a difference in the patient being on time between smartwatch and verbal reminders. The chi-square test was not significant $\chi 2$ $(1, N = 30) = .159$, *p(one-sided)*> .05; suggesting that there is no difference between the smartwatch and verbal condition. In both conditions over 25% of the PM tasks was performed on time.

Figure 1a. Results patient 1 absolute time error (absolute difference in minutes between the time at which a prospective memory assignment was carried out and the time it was intended. Data points show the assignments during a week in which either verbal reminders were given or smart watch reminders. When task/ action carried out did not correspond to what was intended it was scored as incorrect).

Precision of the content of the PM tasks. A Pearson's chi-square test of contingencies (with $\alpha = .05$) was used to evaluate whether there was a difference in precision of PM tasks between smartwatch and verbal reminders. The chi-square test was not significant $\chi 2$ $(1, N = 30) = .370$, $p > .05$; suggesting that there is no difference between the smartwatch and verbal condition (Table 4 & Figure 1a). 85% of the PM tasks were performed correct in both conditions.

Table 4. Descriptive statistics of the precision of the content of the PM tasks per condition.

Precision of the Content	Condition	Mean	SD
PT1	Smartwatch	.87	.35
	Verbal	.93	.26
PT2	Smartwatch	.33	.49
	Verbal	.60	.50
PT3	Smartwatch	.93	.26
	Verbal	.93	.26

Temporal Gradient. Figure 1b-c show the performance of patient 1 on each day of the week. In the smartwatch condition we see that patient 1 performs the task closer to the intended time later in the week. There seems to be a small learning effect in this condition. In the verbal condition we do not see much of a difference in time accuracy over the course of 1 week.

Free recall of PM tasks from episodic memory. A Pearson's chi-square test of contingencies (with $\alpha = .05$) was used to evaluate whether there was a difference in retrospectively remembering which PM tasks had to be carried out during the day of between smartwatch and verbal reminders The chi-square test was not significant $\chi 2$ $(1, N = 30) = .080$, $p > .05$; suggesting that there is no difference between the smartwatch and verbal condition.

Source and temporal order memory. Patient 1 correctly answered the question: "how they were reminded to do the PM tasks (i.e., verbally or by the smartwatch)" 4 out of 5 days in the smartwatch condition and 0 out of 5 days in the verbal condition (appendix 5). He correctly answered the question: "in what order did you perform the PM tasks" 9 out of 15 days in the smartwatch condition and 0 out of 15 days in the verbal condition. Patient 1 performed better on both source and temporal memory in de smartwatch condition

Relationship performance on the PM tasks and retrospective episodic memory for the PM tasks. Overall, when including both conditions, patient 1 had nine successful PM performances (correct and on time). Six of these correctly performed PM tasks were remembered at the end of the day. From the 21 unsuccessfully performed PM tasks, patient 1 remembered six. Relatively patient 1 had more correct responses when he performed the PM task correctly.

Results patient 2

Time accuracy on PM tasks.

Absolute time error. The Mann–Whitney *U*-test indicated that there was no significant difference with regards to time accuracy on PM tasks between the smartwatch condition (*Mean Rank* = 17.17, $n = 15$) and the verbal condition (*Mean Rank* = 13.83, $n = 15$), $U = 87.500$, $z = -1.399$ (corrected for ties), $p = .162$ (Table 3 & Figure 2a).

Categorical time error. A Pearson's chi-square test of contingencies (with $\alpha = .05$) was used to evaluate whether there was a difference in the patient being on time between smartwatch and verbal reminders. The chi-square test was not significant $\chi 2$ $(1, N = 30) = .159$, *p(one-sided)*> .05; suggesting that there is no difference between the smartwatch and verbal condition. Over 10% of PM tasks were performed on time in both conditions.

Precision of the content of the PM tasks. A Pearson's chi-square test of contingencies (with $\alpha = .05$) was used to evaluate whether there was a difference in precision of PM tasks between a smartwatch and verbal reminders. The chi-

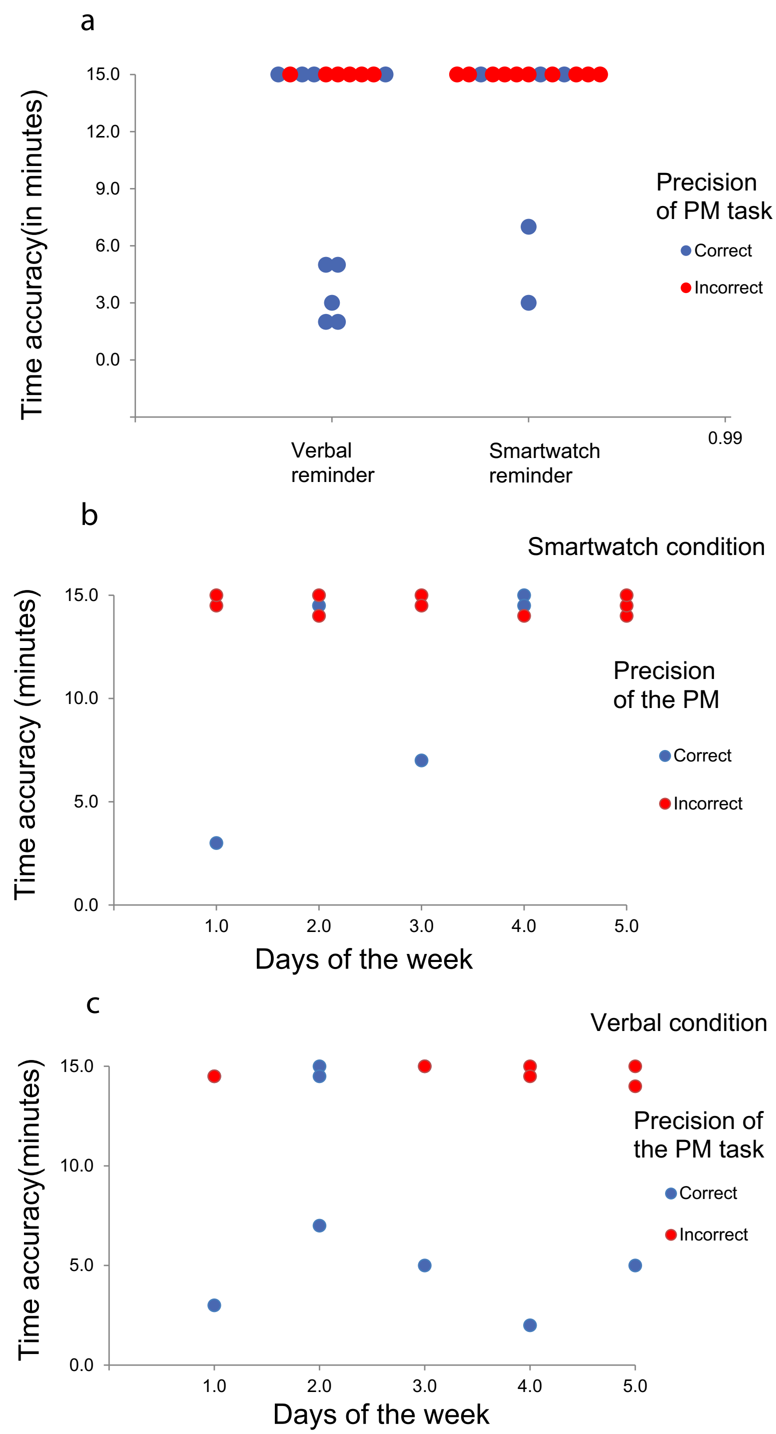

Figure 2. (A) Results patient 2 absolute time errors (absolute difference in minutes between the time at which a prospective memory assignment was carried out and the time it was intended. Data points show the assignments during a week in which either verbal reminders were given or smart watch reminders. When task/ action carried out did not correspond to what was intended it was scored as incorrect).(B) Performance over time patient 2 – smartwatch condition.(C) Performance over time patient 2 – verbal condition.

square test was not significant $\chi2$ (1, N = 30) = 2.143, $p > .05$ (Table 4 & Figure 2a). 34% of the PM tasks were performed correct in the smartwatch condition, and 60% in the verbal condition.

Temporal factor. Figure 2b-c shows the performance of patient 2 on each day of the week. In both conditions we see no difference between the start and end of the week on precision of the PM task and time accuracy.

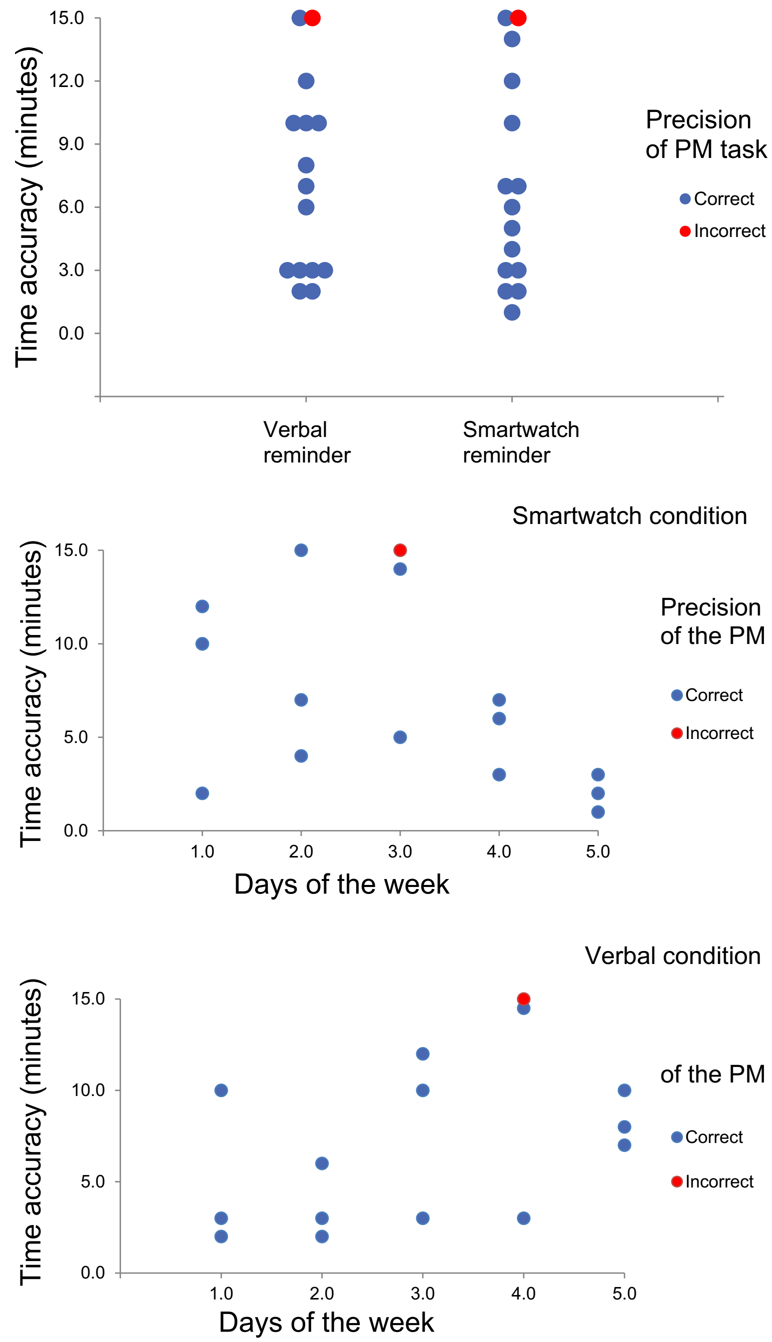

Figure 3. (A) Results patient 3 absolute time error (absolute difference in minutes between the time at which a prospective memory assignment was carried out and the time it was intended. Data points show the assignments during a week in which either verbal reminders were given or smart watch reminders. When task/ action carried out did not correspond to what was intended it was scored as incorrect).(B) Performance over time patient 3 – smartwatch condition.(C) Performance over time patient 3 – verbal condition.

Free recall of PM tasks from episodic memory. A Pearson's chi-square test of contingencies (with **α** = .05) was used to evaluate whether there was a difference in retrospectively remembering which PM tasks had to be carried out during the day of between smartwatch and verbal reminders The chi-square test was not significant $\chi 2$ (1, N = 30) = .144 $p > .05$; suggesting that there is no difference between the smartwatch and verbal condition.

Source and temporal order memory. Patient 2 correctly answered the question: "how they were reminded to do them (i.e., verbally or by the smartwatch)" 5 out of 5 days in both conditions. He correctly answered the question: "in what order did you perform the PM tasks" 0 out of 15 days in both conditions (appendix 5). Patient 2 performed the same in both conditions on source and temporal order memory.

Relationship performance on the PM tasks and retrospective episodic memory for the PM tasks. Patient 2 had 6 successful PM performances. Three of them were remembered at the end of the day. From the 24 unsuccessfully performed PM tasks patient 2 remembered three tasks at the end of the day. Relatively patient 2 had more correct responses when he performed the PM task correctly.

Results patient 3

Time accuracy on PM tasks.

Absolute time error. The Mann–Whitney *U*-test indicated that there was no significant difference on time accuracy on PM tasks between the smartwatch condition (*Mean Rank* = 15.2, *n* = 15) and the verbal condition (*Mean Rank* = 15.8, *n* = 15), *U* = 107.500, *z* = –.209 (corrected for ties), *p* = .834 (Table 3 & Figure 3a).

Categorical time error. A Pearson's chi-square test of contingencies (with **α** = .05) was used to evaluate whether there was a difference in the patient being on time between smartwatch and verbal reminders. The chi-square test was not significant $\chi2$ (1, *N* = 30) = .556, *p(one-sided)*> .05; suggesting that there is no difference between the smartwatch and verbal condition. Over 50% of the PM tasks were performed on time in both conditions.

Precision of the content of the PM tasks. A Pearson's chi-square test of contingencies (with alpha = .05) was used to evaluate whether there was a difference in precision of PM tasks between smartwatch and verbal reminders. The chi-square test was not significant $\chi2$ (1, *N* = 30) = .000, *p* > .05 (Table 4 & Figure 3a). 90% of the PM tasks were performed correct in both conditions.

Temporal factor. Figure 3b/c shows the performance of patient 3 on each day of the week. In the smartwatch condition we see that patient 3 performs the task much closer to the intended time during the last 2 days compared to the previous days. A learning effect can be seen here. However, in the verbal condition patient 3 performed the PM tasks closer to the intended time in the beginning of the week compared to later that week.

Free recall of PM tasks from episodic memory. A Pearson's chi-square test of contingencies (with **α** = .05) was used to evaluate whether there was a difference in retrospectively remembering which PM tasks had to be carried out during the day of between smartwatch and verbal reminders The chi-square test was not significant $\chi2$ (1, *N* = 30) = 1.15, *p* > .05; suggesting that there is no difference between the smartwatch and verbal condition.

Source and temporal order memory. Patient 3 correctly answered the question: "how they were reminded to do them (i.e., verbally or by the smartwatch)" 5 out of 5 days in both conditions. She correctly answered the question: "in what order did you perform the PM tasks" 15 out of 15 days in both conditions (appendix 5). Patient 2 performed the same in both conditions on source and temporal order memory.

Relationship performance on the PM tasks and retrospective episodic memory for the PM tasks. Patient 3 had 18 successful PM performances. 16 of these correctly performed PM tasks were remembered at the end of the day. However, from the 12 unsuccessfully performed PM tasks, patient 3 remembered 10 of them afterward. Hence there was not much of a difference between the correctly carryout a PM task against not correctly doing this with respect to later remembering the task.

Patients' preference. At the end of the two testing weeks, patient 3 reported that she preferred the smartwatch. Patient 1 noted that though, both conditions were fine, the smartwatch made it easier to complete the tasks. Patient 2 stated that he did not want either of the external memory aids (appendix 7). The indicated preferences are in line with the comments patients gave each day on their respective external memory aid. Patient 3 clearly showed the most positive response to the smartwatch and even gave feedback on how to improve it. In most of his comments, patient 1 indicated that the watch was easier than the verbal reminders. Even on days when he only had so say something about the verbal reminders, he started talking about the watch again (which he used the week before). Patient 2 stated on all occasions that he did not want any help from either the researcher or the smartwatch.

Non-inferiority design analyses. One of the reviewers kindly pointed out that an inferiority analysis design should have been considered for the present research. A non-inferiority design can prove the equivalence between two conditions (Heck et al., 2020). For this the investigators must specify a non-inferiority margin (delta) that states how similar the performance of a new intervention must be relative to the standard treatment to be considered "non-inferior". We have decided to follow reviewer's suggestion and conducted a non-inferiority design analysis. We have taken the inverse hypothesis stating that the smart watch works worse on prospective memory performance than the verbal reminders as the null hypothesis. We choose a non-inferiority margin of 1/15 (15 being the number of trials used in both conditions), making .067. The non-inferiority between the smartwatch and verbal reminders was analyzed by calculating the 95% confidence interval of the observed difference in timeliness and precision of the PM task between the conditions and comparing that to the chosen non-inferiority margin.

We observed in patient 1 that, regarding timeliness and precision, the smartwatch the null hypothesis could not be rejected, p > .05, This was also the case for patient 2 (p > .05) and patient 3 (p > .05). Taken together, according to the non-inferiority design, the hypothesis that the smartwatch is inferior to the more standard procedure of verbal reminders, can not be rejected in all three patients. It should be noted that choosing a non-inferiority margin after knowing the results is not correct (Angeli et al., 2020). Therefore these results mainly have a heuristic value.

Discussion

Deficits in episodic memory and EF are two core symptoms of KS syndrome. These deficits typically lead to an impaired PM in KS patients and limit the ability to live independently. Earlier studies have already suggested that one way to improve PM in KS patients is offered by external memory aids. The aim of the present study was therefore to further investigate the effectiveness of a smartwatch as an external memory aid for everyday PM tasks in KS patients. Three patients were tested and their data was analyzed as three separate single-case studies. It was hypothesized that a memory aid could be as useful as verbal reminders by a nurse.

The results of these case studies, when looking at the chi-square analysis, showed that time accuracy on PM tasks did not significantly differ between verbal reminders and reminders provided by the smartwatch. Two patients performed 10% of the PM tasks on time, whereas the third patient performed over 50% of the PM tasks on time. The precision of the task (whether or not the correct task was executed) did not significantly differ between the conditions for all three patients. Taken together, these findings suggest that a smartwatch is as beneficial as verbal reminders as an external memory aid for PM tasks in KS patients. These results are in line with our hypothesis. This conclusion should be taken with care because it is based on accepting the null-hypothesis. Unwarranted conclusions on basis of no difference findings have been criticized over the years (Frick, 1996).

However, in light of our original hypotheses that the smart watch would work as well as the more standard procedure of verbal reminders, one of the reviewers kindly pointed out that an inferiority analysis design should have been considered for the present research. We have decided to follow the reviewer's suggestion and conduct a non-inferiority design analysis in which the null hypothesis was tested that the smart watch works worse on prospective memory performance than the verbal reminders. This non-inferiority design analysis showed that this reversed null-hypotheses: could not be rejected. The classical and the alternative analysis as such appear to contradict each other. However, they both have their limitations. We address these further below. Taken together we believe to have demonstrated the usefulness of the smartwatch as an external memory aid for PM tasks in daily life.

Interestingly, the results also indicate that patient 1 and 3 preferred the smartwatch over the verbal reminders. Patient 3 stated "It is very annoying to constantly be reminded by everyone, the smartwatch is much nicer. With the smartwatch I'm not constantly bothered by the nursing staff". Patient 2 did not have any preference and did not see any need in getting reminders. Moreover, there seems to be a relationship between the performance on the PM tasks and retrospective episodic memory for the PM tasks in two out of three patients. There was no difference in the free recall, source- and temporal order memory between the two conditions. Lastly only patient three showed a small learning effect in performance during the week (Figure 3b/c).

The study of Lloyd et al. (2019) was the first to use a smartwatch as an external memory aid in KS. Here, the authors reported that time accuracy was improved with a smartwatch compared to a phone as an external memory aid or no aid. In addition, the smartwatch and the phone were more effective than no aid for the precision of the task. These findings are in line with the results of our study, showing that a smartwatch is a beneficial external memory aid for PM tasks in KS patients. There were some particular differences between our protocol and the protocol used by Lloyd et al. (2019). Compared to Lloyd et al. (2019) our protocol had reminders in all conditions, whilst Lloyd et al. (2019) had one condition with no reminders. For KS patients living independently at home, the "no aid" condition from Lloyd's study might be more accurate to use as a comparison to the benefits of a smartwatch. However, most KS patients are unable to live independently and therefore stay at a nursing home (Kopelman et al., 2009). For these patients the verbal reminders might be more accurate to use as comparison, which could be a possible benefit of our study. Moreover, in our protocol the patients had different levels of cognitive functioning, compared to one high functioning patient (PhD degree, IQ>120) in the study of Lloyd et al. (2019). Both studies took place at the Korsakoff's center Slingedael in Rotterdam. However, in the current study the patients had to perform PM tasks that were relevant to their daily live in the nursing home, whilst in the study of Lloyd et al. (2019) the patient performed rather arbitrary tasks. Taken together, the results of Lloyd et al. (2019) and our study demonstrate the potential of a smartwatch as an external memory aid to improve PM in KS patients.

Importantly, in the study of Lloyd et al. (2019), the patient often took off the watch because he did not find it comfortable. This could have negatively affected the performance of the patient on the PM task, since the device is to be used as a watch. In our study only patient 2 had a problem with wearing the watch. He even got angry saying that he did not want to wear the watch constantly and that he would put it on again after lunch. These agitated reactions were reported before in KS patients who were asked to use assistive technology (Oudman et al., 2015a). However, this patient also negatively responded to the verbal reminders, stating that he could do the tasks on his own. Patients 1 and 3 had no problems with wearing the watch all day. Patient 1 needed 1 day to get used to it and, at the end of the testing week, patient 3 even thought it was a shame that she had to take it off. Hence, for these two patients study results were not negatively affected by a possible discomfort of wearing the watch, which cannot be said about previous studies. Therefore, the current results are an important addition to the existing literature.

Furthermore, in our study, all three patients scored below the healthy cutoff score on a cognitive screening test (i.e., MoCA; Oudman et al., 2015b). However, the extent of cognitive deficits varied between the three patients; with patient 3 scoring the highest and patient 2 scoring the lowest. Patient 3 also performed best on the memory tests, while patient 1 performed best on the attention and EF tests. Patient 2 had the lowest performance levels in the attention and EF tests and was even unable to finish some of the tasks. Taking all test scores together, patient 3 can be considered to be the highest functioning and patient 2 the lowest functioning participant. These differences in overall cognitive functioning were reflected in patients' performance on the PM tasks. Regarding time accuracy, the results indicate that overall patient 3 executed the PM tasks closest to the instructed target times in both conditions. With respect to precision of the executed PM tasks, patient 1 and 3 performed more tasks correctly than patient 2 in both conditions. Interestingly, the different levels of cognitive functioning and PM performance were also reflected in patient's preferences for either condition: patient 1 and 3 preferred the smartwatch and patient 2 had no preference. This is in line with previous studies reporting a connection between the level of cognitive functioning and the effect of an electronic external memory aid. For instance, De Joode et al. (2010) stated that the effect of their electronic device was associated with the level of cognitive functioning. Consistently, the KS patient in the study of Lloyd et al. (2019) was also a high functioning individual and benefited from the smartwatch. Moreover, the study of Lloyd et al. (2020) showed that KS patients with more intact cognitive functioning, based on their MoCA score, benefit significantly more from training on PM task performance than those with more impaired cognitive functioning. Taken together, it seems that higher functioning KS patients experience more benefits from an electronic external memory aid.

One of the strengths of the current study is that we used, for the first time, a very systematic measurement of PM performance over multiple days. Furthermore, we increased the external validity by implementing tasks relevant to daily life. We have also identified a more specific target group for whom the smartwatch could be beneficial, namely high functioning KS patients. Lastly, we have asked patients about their opinion on both verbal and smartwatch reminders. This gives us an insight into the needs and thoughts of the KS patients, which helps to further specialize the smartwatch for the needs of the patients.

Importantly a number of limitations are also worth mentioning. s. Similar to de Joode et al.'s study (2013), the smartwatch did not always correctly synchronize the information entered by the researcher. If new information had to be updated, during the testing day, the researcher had to take the watch from the patient for a couple of minutes to update the watch correctly. Furthermore, the smartwatch did not constantly show the time, but the screen was black unless a button was pressed. In the current study patients kept on forgetting this and often complained that they could not see the time, which could have influenced the time accuracy on PM tasks. Future studies should either use a smartwatch that always shows the time or train patients to press the button whenever they want to see the time (Oudman et al., 2015a). Lastly an important limitation of this study is that we added the non-inferiority design and margin after already knowing the outcomes. A non-inferiority design can prove the equivalence between two conditions (Angeli et al., 2020). For this the investigators must specify a non-inferiority margin (delta) that states how similar the performance of a new intervention must be relative to the standard treatment to be considered "non-inferior". It is critically important that the non-inferiority trial is specified prior to the initiation of the study (a priori hypothesis). This however was not the case in our study. We have chosen post hoc a delta of .067, based on the fact that we had 15 data points per condition . By doing this we limited how much our knowledge of the performances of the patients in both conditions influenced the margin we chose.

A further limitation that apples to both the classical null hypothesis testing and non-inferiority design was the fact that the total number of trials was limited to only 15 per condition. The reason for this was that the practical circumstances of the clinical did not allow for longer testing. Future studies should try to deal with this.

In summary, we demonstrated that both the smartwatch and the verbal reminders were beneficial as an external memory aid for PM tasks in KS patients. Two out of three patients even preferred the smartwatch over the verbal reminders, saying that it gave them an increased feeling of independence, which could potentially lead to a better quality of life. Most importantly, since the smartwatch is just as effective as verbal reminders, the smartwatch could take off some off the workload of the nursing staff. Moreover, there is first evidence that high functioning KS patients may benefit more from an external memory aid than low functioning KS patients. Taken together, this present study shows the possible benefits of a smartwatch over verbal reminders, if addressed to higher functioning KS patients.

Acknowledgments

We would sincerely like to thank Herbert Hoijtink for taking the time to meet with us and give his thoughts about the statistics.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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Appendix 1. PM tasks, performance and memory – Patient 1 smartwatch condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Bring the yellow envelop to the front desk	0	0	0	1
1	Bring back the grocery card to the cafeteria	0	0	0	1
1	Set the table	0	0	0	1
2	Bring the yellow envelop to the front desk	0	0	1	1
2	Bring back the grocery card to the cafeteria	0	0	1	1
2	Get the mail from the front desk	0	0	1	1
3	Bring the yellow envelop to the front desk	1	1	1	0
3	Bring back the grocery card to the cafeteria	1	0	1	0
3	Go to bingo	0	1	1	0
4	Bring the yellow envelop to the front desk	0	0	1	0
4	Set the table	0	0	1	0
4	Get the mail from the front desk	0	1	1	0
5	Bring the yellow envelop to the front desk	1	1	1	1
5	Bring back the grocery card to the cafeteria	0	0	1	1
5	Get the mail from the front desk	1	1	1	1

* 0 = incorrect response/ performance, 1 = correct performance
** Correct performance = on time + correct task.

Appendix 2. PM tasks, performance and memory – Patient 1 Verbal condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Bring the yellow envelop to the front desk	1	1	0	0
1	Bring back the grocery card to the cafeteria	0	0	0	0
1	Set the table	1	0	0	0
2	Bring the yellow envelop to the front desk	0	0	0	0
2	Bring back the grocery card to the cafeteria	0	0	0	0
2	Get the mail from the front desk	0	0	0	0
3	Bring the yellow envelop to the front desk	0	0	0	0
3	Bring back the grocery card to the cafeteria	1	0	0	0
3	Go to bingo	0	1	0	0
4	Bring the yellow envelop to the front desk	0	0	0	0
4	Set the table	0	1	0	0
4	Get the mail from the front desk	0	1	0	0
5	Bring the yellow envelop to the front desk	1	0	0	0
5	Bring back the grocery card to the cafeteria	1	1	0	0
5	Get the mail from the front desk	0	1	0	0

Appendix 3. PM tasks, performance and memory – Patient 2 Smartwatch condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Go to the gym	1	1	1	0
1	Change the garbage bag	0	0	1	0
1	Go to the workplace	0	0	1	0
2	Set the table	0	0	1	0
2	Water the plants	0	0	1	0
2	Go to the gym	0	0	1	0
3	Wash your clothes	0	0	1	0
3	Buy cigarettes at the store inside the facility	0	0	1	0
3	Go to the workplace	1	1	1	0
4	Go to the workplace	0	0	1	0
4	Change the garbage bag	0	1	1	0
4	Go to the common area to play billiards	0	1	1	0
5	Go to the creative society	0	0	1	0
5	Go to the workplace	0	1	1	0
5	Go to the gym	0	1	1	0

Appendix 4. PM tasks, performance and memory – Patient 2 Verbal condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Go to the gym	1	0	1	0
1	Change the garbage bag	0	0	1	0
1	Go to the workplace	0	0	1	0
2	Set the table	1	0	1	0
2	Water the plants	1	1	1	0
2	Go to the gym	0	1	1	0
3	Wash your clothes	0	0	1	0
3	Buy cigarettes at the store inside the facility	0	0	1	0
3	Go to the workplace	1	1	1	0
4	Go to the workplace	1	1	1	0
4	Change the garbage bag	0	0	1	0
4	Go to the common area to play billiards	0	0	1	0
5	Go to the creative society	0	0	1	0
5	Go to the workplace	0	0	1	0
5	Go to the gym	0	1	1	0

Appendix 5. PM tasks, performance and memory – Patient 3 Smartwatch condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Go to the gym	0	1	1	1
1	Go to lunch	0	1	1	1
1	Go to the workplace	1	1	1	1
2	Go to the creative society	0	0	1	1
2	Go to lunch	1	1	1	1
2	Go to the creative society	1	1	1	1
3	Load the dishwasher	0	1	1	1
3	Wash your clothes	1	1	1	1
3	Unload the dishwasher	0	1	1	1
4	Go to the gym	1	1	1	1
4	Set the table	1	1	1	1
4	Go to the workplace	1	1	1	1
5	Go to breakfast	1	1	1	1
5	Clean your room	1	0	1	1
5	Take your medication	1	0	1	1

Appendix 6. PM tasks, performance and memory – Patient 3 Verbal condition

Day	PM task	Performance	Episodic memory	Source memory	Temporal memory
1	Go to the gym	1	1	1	1
1	Go to lunch	1	1	1	1
1	Go to the workplace	0	1	1	1
2	Go to the creative society	1	1	1	1
2	Go to lunch	1	1	1	1
2	Go to the creative society	1	1	1	1
3	Load the dishwasher	1	1	1	1
3	Wash your clothes	0	1	1	1
3	Unload the dishwasher	0	1	1	1
4	Go to the gym	0	1	1	1
4	Set the table	1	1	1	1
4	Go to the workplace	0	0	1	1
5	Go to breakfast	0	1	1	1
5	Clean your room	0	1	1	1
5	Take your medication	1	1	1	1

Appendix 7. Patients' preference each day

	PT1	PT2	PT3
Smartwatch Day 1	It's good	Not so special, I can do it myself	I changed my mind. It's actually very useful,
Smartwatch Day 2	Very easy	I'm just not used to it	I'm doubtful but I think it could be useful
Smartwatch Day 3	I don't mind it	Not sure, it does not add much	I should be able to do it on my own but for something's, e.g., medication, it could be helpful
Smartwatch Day 4	It's good	I already know what to do without help	It's very useful but it's a very big watch
Smartwatch Day 5	It's very easy	I already know what to do without help	Already the last day? I liked it but it depends on what task I had to perform
Verbal Day 1	I prefer the watch, it's easier	I already know what I have to do	Another person whining
Verbal Day 2	It's both fine for me	I already know what I have to do	I feel more independent with the watch
Verbal Day 3	It's both fine for me	I don't need help	A lot of people say things to me so I prefer the watch
Verbal Day 4	The watch was very easy	I don't need help	Another whiner!
Verbal Day 5	The watch was very easy	I can do it myself	Terrible, so many people tell me what to do. I prefer the watch
Overall preference	There both fine but the smartwatch is easier.	I don't care, I do it myself	Definitely the smartwatch. No one is bothering me and I am more independent