Efficacy of a micro-prompting technology in reducing support needed by people with severe acquired brain injury in activities of daily living: A randomised control trial

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Acknowledgements: Research supported by a grant from the Chief Scientist Office, Scottish Government (CZH/4/598). Thanks to Michael Oddy, Paula Gribben and Donna Lindop for consultation on the needs of persons with brain injury. Thanks to Naomi Bowers for help with data collection. Thanks to the Rehabilitation Support Workers who allowed their scaffolding of sequences to be recorded and used in the development of Guide activity protocols. We are forever indebted to the service users who agreed to participate in the development and clinical trial phases of this study.

This is an Accepted Manuscript of an article published by Wolters Kluwer in the Journal of Head Trauma Rehabilitation on 29 Nov 2017, available at https://insights.ovid.com/pubmed?pmid=29194177.

Potential conflict of interests: The article reports the efficacy of a micro-prompting device (called 'Guide'), developed with support from the Chief Scientist Office, and, as an Android and iOS compatible application, with support from the Disabilities Trust, a not-for-profit organisation, parent charity of the Brain Injury Rehabilitation Trust and therefore employer of SDSR, BON and LON. No other potential conflicts of interest were identified.

Abstract

Objective: Evaluation of the effectiveness of an automated interactive prompting technology in supporting the morning routine. The morning routine included the following activities of daily living: maintaining personal hygiene and dressing.

Setting: An inpatient neuro-rehabilitation hospital.

Participants: Persons with acquired brain injury, who required prompting when following their morning routine (n=24), but were not limited by physical disability or dysphasia, took part in the study. Participants (67% TBI) had impairment on indices of memory and executive function.

Design: A randomised control trial evaluated the effect of an automated interactive micro-prompting device on the number of prompts by trained staff required for successful completion of the morning routine.

Main Measures: Study specific checklists assessed sequence performance, errors and verbal prompts required over baseline, rehabilitation as usual, intervention and return to baseline conditions.

Results: The intervention significantly reduced the support required to complete the task compared with rehabilitation as usual.

Conclusions: Micro prompting technology is an effective assistive technology for cognition, which reduces support needs in people with significant cognitive impairments.   [169 words]

This is an Accepted Manuscript of an article published by Wolters Kluwer in the Journal of Head Trauma Rehabilitation on 29 Nov 2017, available at https://insights.ovid.com/pubmed?pmid=29194177.

Keywords:

Brain injuries; Activities of Daily Living; Assistive Technology; Cognition; Rehabilitation; Caregiving

INTRODUCTION

Assistive technology for cognition

Assistive technology for cognition is that which enables, enhances or extends cognitive function. [1] Technology has long been studied as an extension of human abilities. [2,3] However, it is only more recently that attention has focused on how technologies might enhance and extend cognition. [4,5]

Prompting by carers

People who need carer support with activities of daily living and those who are independent can be differentiated by cognitive profiles [6]. Deficits in performance of activities of daily living are related to performance on executive function tasks. [7] The predominant compensations for difficulties in activities of daily living are formal or informal caregivers [8], and observations of caregiver behaviour reveals that they are often providing verbal scaffolding to augment cognitive performance, such as prompting, reminding, drawing attention to and structuring plans of action [9–11]. Thus the type of support provided by carers suggests that carers are primarily scaffolding executive and memory functions. Given that such support is time-consuming to deliver, recent research has examined whether ATC might

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be a viable alternative to supporting executive and memory function in people with cognitive impairment during activities of daily living.

Prompting technologies

Prompting technologies are a class of ATC [1,12], that can increase independent activity in persons usually requiring carer input [13]. Prompting devices store information about actions to be carried out and provide timely cues [14]. They are divided into two functional classes: prospective prompting devices and micro-prompting devices.

Prospective prompting devices remind users to engage in an activity (e. g. Take medication, visit the dentist or water the houseplants) and operate via portable or wearable personal digital assistants (PDAs) such as mobile phones [15], pagers [16], voice recorders [17] and smartwatches that give reminders [18], by way of text alerts or audio cues. Prospective memory aids can be used to give reminders to ambulant persons [15–18] or to persons in a set location within the home [19], care home [20], or vehicle [21]. These devices support retention and acting on future intentions in the medium and long term.

Micro prompting devices support complex task performance. Performing complex goal-directed tasks relies on a number of related cognitive abilities such as , task organization, attending to the task, set maintenance, set shifting (between activities), retaining the intention and recall of problem solving heuristics. Micro-prompting devices are designed to support these cognitive functions required when multiple steps must be carried out in a specific order. Trials to date have supported sequences such as hand-washing [22], donning of prosthetic limbs [23], tooth brushing [24] and blood glucose checking [25].

A review of 91 studies on assistive technologies for cognition, concluded that more randomized control trials were necessary, but, that such testing should focus on ATC functions (rather than individual devices, which are rapidly changing) [26]. The present article reports on the first RCT of a micro-prompting device that emulates caregiver scaffolding of executive and memory function using audio prompts and verbal interaction. This study tests whether an audio prompting device can be an effective cognitive orthotic for individuals with acquired brain injury and behavioural dysregulationduring performance of the morning routine.

Research questions

The study aimed to test the hypothesis that interactive verbal scaffolding by a micro-prompting device reduces need for support during performance of the morning routine.

METHOD

Setting

The study was conducted in a specialist acquired brain injury (ABI) rehabilitation centre that provides service to individuals with acquired brain injury and behavioural dysregulation/ disturbances. [27–29].

Participants

One hundred and three adults with acquired brain injury aged 18-65 received rehabilitation at the study site during the test phase of the study. Figure 1 shows recruitment flow-chart enumerating reasons for exclusion and dropout. Comparable research [30], investigating

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errorless learning of a routine in a sample of people with acquired brain injury, found an effect size of 1.2. With this effect size and significance set at the .05 level, a total of 13 participants would allow a power of .80 for detection of a significant difference in learning. To be conservative we aimed to recruit 20 participants. A total of 27 participants were recruited and randomised.

[Insert Figure 1 about here]

The inclusion criteria were: (1) having functional problems in carrying out the morning routine and (2) being able to perform the task if given appropriate verbal prompts. The exclusion criteria were: (1) inability to follow a single sentence verbal instruction (e. g. due to severe dysphasia) or (2) physically unable to perform the given task.

Aetiology of Injury

The aetiology of injury for the majority of the 24 participants was traumatic brain injury (n=16, 66.7%). Of these, eight (50%) had falls, four (25%) had road traffic accidents (all as pedestrians), three (19%) had assaults and one (6%) sustained another form of TBI.

Non-traumatic injuries were sustained by the remaining eight (32.5%). Of these, three sustained subarachnoid haemorrhages (38%), two hypoglycaemia (25%), two had vasculitis (25%) and one had a nutritional deficiency (12.5%). The mean time since brain injury was five and a half years.

MATERIALS

Measures

A ‘Morning Checklist’ (see Appendix) was produced based on the necessary steps for completion of the morning routine and the list of possible errors. All the trials were scored using these checklists by the Brain Injury Rehabilitation Trust’s (BIRT) Rehabilitation Support Workers who noted: number of support worker interventions (an index of independence in the activity, following the methodology of Mihailidis et al. [22]), number of safety critical and general errors (following the methodology of O’Neill et al. [23]), deviations from and repetitions of the necessary sequence (following the methodology of Semkovska et al. [31]). For the person with acquired brain injury there was a rating on an accessible five point scale of how happy they were with the task (referred to as the ‘Satisfaction score’).

Neuropsychological functioning

A neuropsychological profile was obtained for each participant using measures of: premorbid intelligence (Test of Premorbid Function UK); current intellectual ability (Wechsler Adult Intelligence Scale-IV – WAIS-IV); memory (Rivermead Behavioural Memory Test-3); visuospatial function (Perceptual Reasoning Index of the WAIS-IV); language (Verbal Comprehension Index of the WAIS-IV); executive function (Behavioural Assessment of Dysexecutive Function) and emotional state (Hospital Anxiety and Depression Scales).

Micro Prompting Device: Guide

Guide is an audio-verbal interactive micro-prompting software, designed to emulate the verbal prompts and questions provided by carers or support workers. The intervention automatically emulates the naturalistic question and answer dialogue in which a person with how-to knowledge of a task verbally scaffolds the performance of the task by a person without that knowledge. [32] Guide has previously been shown to be effective in supporting

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individuals to don prosthetic limbs [23] and in supporting the morning routine for an individual living at home [33].

The Guide system used had four components: (1) A Windows enabled Dell Precision M4500 PC, Creative T10 speakers and an Acoustic Magic Voice Tracker II directional microphone; (2) Dragon Naturally Speaking speech recognition software; (3) Guide activity protocols (developed during the development and piloting phases) and; (4) the Guide activity protocol player, that is, software which received the verbal responses, matched them to the protocol, and triggered the appropriate prompt.

The Guide systems were located in the participants' bedrooms. There was a software timer which started the audio prompting at a time agreed with the participant: most commonly 8 am. At 8 am the introductory prompt would be given, 'Good morning [name] it's 8 o'clock time to get up'. After a pause, the prompting device would issues further checks (e. g. 'Are you out of bed?'). The user could respond 'yes', 'no' or they could say 'what?' to have the question repeated. In this way the Guide system checked progress through the morning routine and issued the next appropriate prompt given the feedback from the participant.

Procedure

We chose to target the familiar task of getting ready in the morning. The first phase of the study entailed developing a suitable prompting protocol, and the second phase entailed testing it for efficacy against treatment as usual.

Development of activity protocols

We administered semi-structured interviews about the morning routine task to five participants with acquired brain injury, five therapists and five Rehabilitation Support Workers, covering: typical sequence, problems encountered, solutions and strategies for aiding performance. We then recorded 30 sessions where Rehabilitation Support Workers provided prompts to six people with brain injury during the task. These data were analysed using NVivo 8 using procedures of Hierarchical Task Analysis to derive a map of the problem space. [34] The morning routine problem space ranged from the point the user was in bed to when they were up, showered, dressed and ready to have breakfast in good time to begin their rehabilitation program at 10am. The dimensions of the problem space covered all the combinations of prompts and activities that could result in a successful start to the day. It also identified the most common barriers to successful completion of the morning routine (e. g. the person is unmotivated to get up, or the person cannot remember where to find their clothes, or the person goes into bathroom but forgets to take a towel then comes back out sees the clothes and skips the shower step, getting dressed without showering). This analysis was then used to produce the activity protocol, that is, a series of essential prompts and checks, and branching problem solving routines that covered the most common paths through the problem space. The morning routine protocol consisted of seven steps subsuming 40 checks and 40 prompts.

The prompting protocol was programmed into the micro-prompting device and piloted with 10 service users with acquired brain injury, allowing assessment of system operation, usability and use preferences. This gave rise to a refined protocol for the activity of interest. Morning routine had wide preference variation. Thus, when individuals were recruited to the study, we ascertained their morning routine preferences carefully and tailored the comprehensive protocol to that set of preferences (e. g. shaving, lipstick wearing, smoking).

The testing phase

The testing phase comprised a randomised control design experiment. In weeks one and two, participants were recruited to the study if they met the eligibility criteria, informed consent was then sought and the participant was randomly assigned to the intervention or the control groups using the closed envelope method. Baseline assessment (five trials) occurred in week three followed by three weeks (or 15 trials) of test phase (weeks four to six), and two weeks (or 10 trials) of return to baseline (follow-up – weeks seven to eight).

Naturally participants varied in the amount of support they required under ‘rehabilitation as usual’. Some participants always had a Rehabilitation Support Worker with them during the morning routine. In these cases, in the test phase, the support worker was present while Guide was prompting the user through their morning routine and the support worker only intervened if there was a problem. Other users, who usually completed the morning routine without a support worker in the room under ‘rehabilitation as usual’, would be prompted if they came for breakfast in their night clothes or if other aspects of the morning routine had been forgotten (e. g. shaving). In these cases, during the test phase, the Guide system prompted the user in their room without a support worker present. Staff could assess whether there were any errors or omissions in their morning routine when the service user came out of their room into the communal areas. For example, if the person was still wearing night clothes, they would be reminded to change by a member of staff and this would be recorded as a prompt. If they had poor personal hygiene they would be prompted to go and shower. It was quite common for participants who did not have someone with them while they performed their morning routine to require 2 or 3 prompts after they came out of their room to attend to matters they had omitted. The study was designed to assess reduction in number of staff prompts required between baseline and intervention phases. If someone commonly received a number of prompts every day after arriving for breakfast, we wished to determine whether Guide would reduce the probability of needing these prompts. For service users who had a staff member in the room with them we assessed whether Guide would mean a reduction in staff prompts in the room and after they arrived for breakfast. There were no restrictions put on the type or frequency of prompts provided by support workers during the study.

The study specific checklists recording the number of prompts and errors were completed by the Rehabilitation Support Worker supporting the user or, for users not receiving one-to-one support during the morning routine, any Rehabilitation Support Worker on duty. The interactions between the Guide system and the user were also audio-recorded, and these could be reviewed for additional information.

Research Ethics

The study protocol, information sheets, consent forms and recruitment strategy were approved by the Scotland A, Research Ethics Committee (Ref: 10/MRE00/43) on 27 September 2010.

The study was pre-registered, with the Chief Scientist Office of the Scottish Government; the Scotland A, Research Ethics Committee; and with the Foundation for Assistive Technology.

Data analyses

The randomised control trial data were analysed using Stata version 14. Nonparametric tests (Mann-Whitney U) were used to make simple unadjusted comparisons across conditions. The main analysis was conducted using generalized linear mixed models. The effect of the intervention was assessed through the fixed effects of the Phase (baseline, test, and return to baseline) by Group (rehabilitation as usual, intervention) interaction term. The primary outcome for this study was a count (number of support worker prompts) therefore a Poisson distribution was initially assumed. Over dispersion was investigated by fitting negative binomial models and comparing fit relative to the Poisson. A random effect of ‘Participant’ was included in the model to account for the repeated measures within participant and the effects of time were allowed to vary for each individual (accounting for different learning and recovery trajectories for individuals) by including a random effect of ‘Time’ (number of days in the study). Likelihood ratio testing was used to confirm whether the random coefficient was superior to the random intercept only models. Neuropsychological variables were individually tested in the models as fixed effects and significant predictors retained.

RESULTS

Cognitive status of participants

The participants' demographics are summarised on table 1. All participants with traumatic brain injury (n=16, 66.7%), had severe brain injury as indicated by a Glasgow Coma Scale score of 3-8, and post-traumatic amnesia greater than 24 hours. All those with non-traumatic brain injuries (n=8, 33.3%) had severe levels disability on the Glasgow Outcome Scale when referred to the rehabilitation service. The premorbid IQ indicated that participants were in the average range prior to their injury. The current Full Scale IQ indicated that participants were significantly impaired (relative to the index of premorbid ability) and were now in the extremely low range. The memory function standard score was in the extremely low range. The language function (Verbal Comprehension) was in the borderline range, as was the visuospatial function. Importantly, the executive function score was in the extremely low range. Hospital Anxiety and Depression Scale scores were within the low borderline range, with 12 participants meeting the caseness criterion for anxiety and seven meeting caseness for depression.

[Insert Table 1 about here]

Effect of Intervention

The mean scores on the outcome measures by Group (rehabilitation-as-usual or intervention) and Phase (baseline, test, and return to baseline) are shown in Table 2.

[Insert Table 2 about here]

The mixed effects Poisson regression on number of support worker prompts showed a significant interaction between test Phase (baseline, test, and return to baseline) and Group

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(rehabilitation-as-usual vs. intervention). That is, being in the test phase significantly reduced the number of prompts received to a greater extent in participants in the intervention group than in the rehabilitation-as-usual group. The same was true of the return to baseline phase. This confirms that, with the individual trajectories of change over time controlled and the correlation structure of the repeated measures within individuals included in the model, being in the intervention group significantly reduced the number of prompts received during test and return to baseline. The incident rate ratios for the fixed elements of the model and the variance components of the random effects are shown in table 3. There were no differences between groups across the three phases in terms of number of errors, sequence errors or in satisfaction scores.

[Insert Table 3 about here]

DISCUSSION

We have reported on the first randomized control trial for an audio-verbal interactive micro-prompting device. The device was tested with people with severe brain injury and multiple cognitive impairments during the morning routine. Use of the technological system was evaluated as an adjunctive therapy within neurobehavioural rehabilitation, an approach which is evidenced to reduce impairment and increase functional abilities after brain injury. [27,28,32] Against this efficacious rehabilitation-as-usual, the micro-prompting device significantly reduced number of support worker prompts in a familiar task (morning routine). This adds to the evidence of the effectiveness of micro prompting devices established in previous studies. [13,23] The study also demonstrates improvement in individuals with chronic neurobehavioural disability resulting from injuries sustained a number of years prior to the intervention, when

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biological recovery has traditionally been thought to have stabilised. This further extends the evidence that enhancing independence is possible, and rehabilitation is effective in the long-term [27,35,36].

In the test phase, there was a statistically significant effect on number of prompts by carers, showing that these decreased more sharply in the intervention group. Thus, the interactive verbal guidance was an effective support.

Prospective prompting and micro-prompting technologies to date have begun to address the difficulties associated with deficient ‘higher level cognitive functions’. [26] These are the cognitive capabilities which underpin organization and planning, time management, cognitive flexibility, maintaining task set, problem-solving, abstraction, insight and judgment. As these difficulties are common across a variety of conditions, micro-prompting devices, such as Guide, add to the tools available to address sequence performance difficulties.

Limitations

Data from three participants was not available for analysis due to problems with data collection. However these cases were spread across the intervention and control conditions.

Future research

In this study, an activity of daily living was chosen in an attempt to demonstrate the possibility that prompting technologies may increase independence. Many other sequence-critical behaviours underpin patient self-management, and may benefit from micro-prompting support. For example, persons with respiratory illnesses may benefit from step-by-step

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prompting for procedures such as using an inhaler and spacer or nebuliser to deliver medication. Trial of the use of micro-prompting technologies for new behaviours and populations would be of interest. Micro-prompting may also be beneficial to support complex real-world tasks (such as performance at work, management of a daily schedule, following a recipe), in both clinical and non-clinical populations.

The current findings help establish the efficacy of micro-prompting for persons with impairment of memory and executive function. Future research might focus specifically on persons for whom amnestic difficulties primarily explain their difficulty in performing sequences. Effectiveness of micro-prompting in persons with mild cognitive impairment and dementias would have far reaching ramifications for care in an ageing society. [37]

Future research should also focus on triggering of prompting technologies. In this study, the device was activated by a timer in the morning routine. Other triggers might include a physical button placed where the activity is performed (i.e., bedroom or kitchen), so that the user can self-initiate the support. Sensors in the environment detecting location, movement or door opening might be used to trigger the system to ask whether help is required. Finally, the incorporation of input from affect-aware technology, monitoring physiological state via wearables [38] may trigger help at signs of distress.

The considerable economic and social costs of supporting activities of daily living in people with cognitive impairments suggest that a finding in support of micro-prompting devices is significant. Independent replications are encouraged and, to this end, the software will be available at www.guide-research.com. Of equal importance is to further understand the wider benefits of replacing some aspects of the carer's work with technology, for example reducing care-giver strain and increasing self-efficacy.

Table 1. Demographics and cognitive status of participants

	Morning routine		
	Intervention	**Control**	**Total**
N	10	14	24
Male : Female	9:1	13:1	22:2
	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
Age in years	44.18 (11.42)	45.82 (10.34)	45.14 (10.59)
Years since injury	6.38 (10.57)	4.93 (6.59)	5.53 (8.30)
Premorbid function	91.67 (9.03)	96.65 (8.51)	95.08 (8.75)
Intellectual function	68.40 (3.54)	69.92 (8.16)	69.26 (9.40)
Memory function	59.22 (4.63)	66.13 (5.89)	63.61 (6.33)**
Language function	75.67 (11.02)	76.69 (8.76)	76.27 (9.51)
Visuospatial function	79.89 (13.20)	78.39 (9.34)	78.98 (10.74)
Executive function	53.89 (21.63)	59.63 (21.02)	57.28 (20.95)
Anxiety	9.33 (5.32)	9.90 (5.13)	9.67 (5.09)
Depression	8.00 (6.61)	7.49 (3.97)	7.70 (5.07)

Note. * $p < .05$; ** $p < .01$

Table 2. Mean (SD) number of support worker prompts; errors; sequence errors and user satisfaction by Group at Baseline (A), during Intervention (B) and Return to Baseline (A)

	Intervention	**Control**	**Total**
Prompts			
A	2.87 (2.37)	1.95 (2.32)	2.33 (2.33)
B	1.43 (1.72)	2.58 (2.73)	2.15 (2.42)
A	1.63 (1.32)	2.90 (2.96)	2.42 (2.50)
Errors			
A	0.41 (0.48)	0.47 (0.45)	0.45 (0.45)
B	0.24 (0.26)	0.40 (0.47)	0.34 (0.40)
A	0.15 (0.29)	0.46 (0.41)	0.35 (0.39)
Sequence Errors			
A	0.00 (0.00)	1.79 (5.40)	1.09 (4.24)
B	0.05 (0.08)	2.39 (5.75)	1.61 (4.75)
A	0.25 (0.50)	0.30 (0.74)	0.28 (0.65)
Satisfaction			
A	4.58 (0.52)	4.17 (0.24)	4.32 (0.39)
B	3.79 (1.58)	3.48 (0.56)	3.61 (1.02)
A	3.00 (0.00)	4.25 (0.61)	4.07 (0.73)

Note. * $p < .05$; ** $p < .01$

Table 3. Mixed effects Poisson regression on Number Prompts to complete morning routine

Independent variable	**Incident rate ratio**	**95% confidence interval**	***p***
Phase: Baseline	1.00		
Phase: Test	1.43	1.15 - 1.79	<0.01
Phase: Return to Baseline	1.32	0.98 - 1.78	0.07
Intervention group	1.84	0.68 - 4.98	0.23
Phase by Group interaction (Baseline)	1.00		
Phase by Group interaction (Test)	0.39	0.27 - 0.57	<0.01
Phase by Group interaction (Return to Baseline)	0.30	0.15 - 0.62	<0.01
Emotional function	1.22	1.10 - 1.34	<0.01
Random effects parameters	Estimate		
Participant	0.01	0.00 - 0 .02	
Time in trial	1.07	0.72 - 1.60	

n = 22 Two cases missing due to missing data for emotional function (anxiety). The results are the same (i. e. intervention group by phase interaction significant) if anxiety is omitted from the model and full sample is tested.

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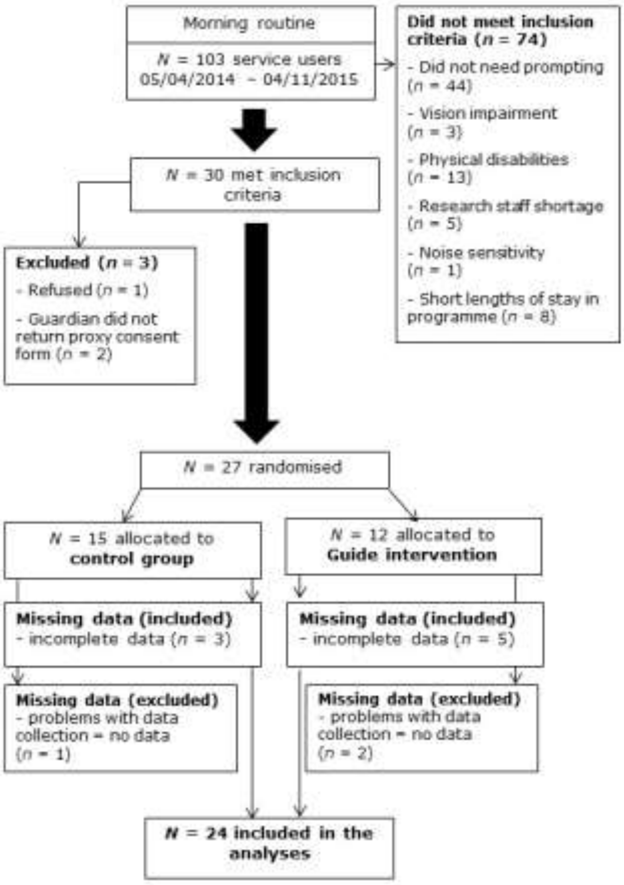
Figure 1. Flowchart for recruitment to the study.



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Appendix

MORNING CHECKLIST

Level of prompting

	M	**T**	**W**	**T**	**F**	**S**	**S**
Wake up							
Get out of bed							
Use toilet							
Wash hands							
Go into shower							
Shower: Wash upper half							
Wash lower half							
Wash hair							
Brush teeth							
Dry self							
Shave: Wet / Dry							
Use deodorant							
Select appropriate clothes							
Find clothes							
Dress							
Brush hair							
Make bed							
Medication prompt by staff Y/N							
Picks up phone/keys/cigarettes							
Rating of personal appearance (out of 10)							
Time up							
Completed by:							

5 = Completes step independently;
4 = Completes step after 1 verbal prompt;
3 = Completes step after 2 verbal prompts;
2 = Completes step after 3 verbal prompts;
1 = Requires physical intervention / assistance to start, continue or complete step;
R = Refuses to complete step;
N/E = No evidence;
N/A = Not appropriate (e. g. woman who does not shave)

Errors (circle Y / N)

	M	**T**	**W**	**T**	**F**	**S**	**S**
Stays in bed until after 10am	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Gets up but goes straight back to bed	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Does not take towel to shower	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Does not take soap /shower gel to shower	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
	M	**T**	**W**	**T**	**F**	**S**	**S**
Does not get all the clothes necessary to be fully dressed	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Does not take shampoo	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Cannot find an item of clothing that is in the room	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Dresses when still wet	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Once out of bed hesitates for 3+ seconds	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Inappropriate clothes chosen for weather	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Dirty /mismatched clothes worn	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Poor personal hygiene	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Unshaven	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N
Forgets phone/keys/cigarettes	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N	Y / N

Sequence errors

	M	**T**	**W**	**T**	**F**	**S**	**S**
No of times repeats a step							
No of steps missed							
No of times stuck on a step							
Time taken							

Other comments

Service user satisfaction

How well do you feel that went?

				
5 Very well	4 Quite well	3 Ok	2 Quite poorly	1 Very poorly

	M	T	W	T	F	S	S
Rating							

This is an Accepted Manuscript of an article published by Wolters Kluwer in the Journal of Head Trauma Rehabilitation on 29 Nov 2017, available at https://insights.ovid.com/pubmed?pmid=29194177.