Perceptions and Effectiveness of a Fully-Automated Brief Behavioral Insomnia Therapy, Delivered by a Virtual Companion, in Older and Young Adults

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ABSTRACT

Background and Objectives: One of the most common sleep disturbances in older people is insomnia. Cognitive-behavioral therapy is the first-line treatment for this condition in older adults, but in-person treatment is costly and often unavailable. In this study, in a group of older and young subjects, we aimed to compare: (1) their initial perceptions of a fully-automated mobile health intervention to manage insomnia, (2) how these perceptions related to treatment completion, and (3) the effects of the intervention on insomnia severity and related outcomes.

Research Design and Methods: A case series study was conducted with a self-selected sample of older (≥ 65 years) and young (18-35 years) adults (*n*=5,660) who downloaded a free app, available in France, that delivers a brief behavioral intervention for insomnia aided by a virtual companion. The 17-day intervention included sleep hygiene and stimulus control recommendations. Primary outcome was treatment completion (yes/no). At the beginning of the intervention, treatment acceptability and trust in the virtual companion were assessed with two short questionnaires (completion rate: 1,597 users). Insomnia was evaluated with the Insomnia Severity Index.

Results: Logistic regression analyses showed that higher credibility and trust in the app's virtual companion were associated with higher odds of treatment completion, but only in older adults (Trust scores x Age group: OR=1.12, [95%CI=1.01-1.25], $p < .05$, and Credibility scores x Age group: OR=1.25, [95%CI=1.06-1.47], $p < .01$). Within the subset of users who completed the intervention (*n*=289), insomnia remission (χ^2=2.72, NS) and insomnia response rates (χ^2=2.34, NS) were comparable across both groups.

Discussion and Implications: This brief behavioral intervention appears to be efficacious for the self-management of insomnia symptoms in older adults. The integration of persuasive

interaction elements, such as avatars and virtual coaches, in fully-automated interventions could be particularly useful to stimulate older adults' engagement.

Clinical Trial Registration: NCT05074901

TRANSLATIONAL SIGNIFICANCE

Access to in-person cognitive-behavioral therapy, the first-line treatment option for geriatric insomnia, is restricted for a good proportion of individuals in need. Mobile health offers the potential to reduce this gap. This study shows that a smartphone-based behavioral intervention, delivered by a virtual companion, reduces symptoms of insomnia in older adults. It also suggests that integrating persuasive interaction elements, such as avatars and virtual coaches, could be particularly useful to stimulate older adults' engagement with this type of interventions.

KEYWORDS

Sleep, Mobile Health Intervention, User engagement

BACKGROUND AND OBJECTIVES

One of the most common sleep disturbances in older people is insomnia, and the prevalence of insomnia symptoms increases with age (Doghramji, 2006; Patel et al., 2018). Among older adults, untreated insomnia is an important risk factor for depression(Riemann et al., 2020; Sadler et al., 2013), cognitive decline(Gebara & Karp, 2020; Robbins et al., 2020) and falls(Chen et al., 2017). Although the usual approach to treat insomnia includes the prescription of medication, pharmacotherapy is not considered a safe option for treating this condition in older adults(Bloom et al., 2009). Studies have consistently found increased risks of fracture in older adults who use benzodiazepine or other related drugs (Bakken et al., 2014; Berry et al., 2013; Lin et al., 2014). Nonpharmacological approaches such as cognitive-behavioral therapy for insomnia (CBT-I), whose goal is to restructure a person's sleeping behaviour, is considered as the first-line treatment option, especially for geriatric insomnia (Bloom et al., 2009; Chen et al., 2023; Riemann et al., 2022). Nonetheless, access to a sleep specialist in CBT-I is restricted for many patients in need, and most primary care physicians are not sufficiently trained to perform CBT-I (Espie, 2009; Koffel et al., 2018).

Rapid advances in telecommunication and mobile technologies worldwide have created new opportunities in delivering healthcare services, providing ubiquitous low-cost access to many specialized behavioral interventions such as CBT-I(Drerup & Ahmed-Jauregui, 2019). Community-dwelling older adults may particularly benefit from using these digital therapeutics(Gulliford & Alageel, 2019). Indeed, they face additional challenges, related to transportation and mobility, that all lead to a poorer access to psychotherapy (Wuthrich & Frei, 2015). .

Although older adults have been traditionally seen as unwilling to use digital technology(Askari et al., 2020; Czaja et al., 2006), there is mounting evidence challenging this prevailing technophobic stereotype. A study investigating 113 older adults about their use of and attitudes to technology in the context of their home, work, and healthcare, found that they held more positive than negative attitudes about using technologies(Mitzner et al., 2010). This is particularly important in the field of Mobile Health (Mobile health (mHealth) interventions refer to the use of mobile devices to perform health-related interventions), since increasing numbers of older adults own smartphones nowadays. Some studies suggest that older adults are willing to use smartphone technologies to manage their own health(Hauk et al., 2018; Wong et al., 2022) . In the context, our group developed and recently published data on the effects of a smartphone application, named KANOPEE, featuring an abbreviated digital version of CBT to manage insomnia complaints (Dupuy et al., 2022; Philip et al., 2022) and noted that a sizeable proportion of older individuals (≥ 65 years old) were interested in downloading the app. For example, our team's last examination of app downloading data for a given month showed that, of 4192 subjects downloading the app, almost 20% (*n*=818) were 65 years or older. Nonetheless, despite older adults seem to be open to mHealth interventions, a recent review on their engagement suggests that the majority of older adults encounter various barriers to successfully engage with these(van Acker et al., 2023).

The use of apps in smartphones phones and other touchscreen devices is a more cognitively challenging activity for older adults than for younger subjects, since it involves interactive coordination of psychomotor, sensory, and several cognitive capacities that gradually decline with advancing age(Hultsch et al., 1993; van Hooren et al., 2007). These capacities include, for instance, procedural or long term memory, which is required to activate the routines that are necessary to install and start using an app, working or short term memory, that is activated to keep track of

information already processed or to decide on the next step to take, visual search and attentional processes, that are recruited to evaluate which information is more or less relevant. However, research suggests that it is not the cognitive cost that primarily determines the adoption or not of technology by older subjects but the perceived benefit(Melenhorst et al., 2006). The study by Melenhorst et al. evaluating adults' motivation to use of email contradicts the common belief that usability problems (costs) determine older people's use of new technology. This study highlights the crucial role of perceived benefits for successful innovation in older adults. Indeed, when asked the question why they do not use a particular type of technology, older adults point more to the lack of the apparent benefit of using it rather than to the cognitive cost it engenders. This suggests that if older individuals perceive the benefit upfront, their motivation will be high to overcome any obstacles to adopt a technological innovation.

Another important issue to explore is the extent to which self-administered technology-driven interventions are effective for older adults. There is still a paucity of studies examining digital interventions for mental health symptoms, in general (and for insomnia, in particular), in older adults (Boucher et al., 2022; Goodarzi et al., 2023; Vailati Riboni et al., 2022). There is a paucity of research comparing the effectiveness of technology-driven interventions in older and young adults, but previous studies suggests that younger subjects tend to show better outcomes than older individuals(Newman et al., 2003). In the field of insomnia, Vincent and Walsh(Vincent & Walsh, 2013) showed that digitally delivered CBT-I proved sufficient to improve insomnia symptoms particularly in younger adults, thus suggesting that older adults may need more intensive approaches to manage their insomnia. However, recent data suggests that demographic variables, including age, do not seem to moderate the effectiveness of digital CBT-I(Riemann et al., 2022).

In order to maximize the potential that technology administered health interventions offer to older adults, it is important to analyse not only how efficacious they are, but also how older adults perceive and use these interventions. Hence, in these secondary analyses of the effects of KANOPEE to self-manage insomnia complaints we aimed to test the following:

1) Whether the perceptions of the app's features differ in older (≥ 65 years old) and younger subjects (18-35 years old);
2) Whether the initial perceptions of the app's features have a role on app engagement (i.e. completing all the intervention phases) in older and younger subjects;
3) Whether the app intervention produces comparable symptom improvements in older and younger subjects.

RESEARCH DESIGN AND METHODS

Study design, settings and participants

Case series study of a self-selected sample of individuals aged between 18-35 (young adults group) and 65 and older (older adults group) downloading and initiating a free, fully-automated insomnia management programme named KANOPEE, available to the general population in France, during the period April, 22 2020 to February, 13 2022. In order to reach various groups of users, communication about the app was made on the social medias (Instagram, TikTok, Facebook, Twitter) by one of the authors (PP), through national and regional newspapers and TV channels, as well as through the University of Bordeaux and University Hospital in Bordeaux mailing lists. Informed consent was obtained directly on the app by all users before any data collection. For this study's dataset, no exclusion criteria were employed, other than age. We did not include individuals with ages ranging from 36 to 64 years old. The approval of the ethics committee of the

University of Bordeaux was obtained, as well as agreement with respect to the General Data Protection Regulations (GDPR) by the French authorities (CNIL).

Intervention

The app KANOPEE was designed to help users managing their insomnia complaints through interactions with a virtual companion (VC). The VC, named Louise, is an animated character able to engage in face-to-face dialogue through verbal and non-verbal behavior. Louise incorporates human voice and body motion (Figure 1).

The programme is divided into three phases, covering an assessment period of 17 days. After downloading the app, users have access to a screening interview with the VC (phase 1). During this interview, the VC asks users to complete three questionnaires: the Insomnia Severity Index (ISI)(Bastien et al., 2001), the Fatigue Severity Scale (FSS)(Krupp et al., 1989), and the Patient Health Questionnaire-4 (PHQ-4)(Kroenke et al., 2009). Then, visual feedback using a colored line including the traffic lights' three colors (red, orange and green) is provided. The user's score on the ISI is located in one point along the colored line (if it is on the red area, it connotes severe insomnia, if it is on the orange area, it connotes moderate insomnia and if it is in the green area, it connotes mild or no insomnia symptoms) and the user is asked to begin a personalized programme. The first step includes completing a sleep diary. The VC explains why completing a sleep diary is important and stars collecting information from the previous night. Once this step is completed, another screen informs the users that they need to complete the same sleep diary for seven days, every morning, and that, a week later, the VC will re-evaluate their sleep in another interview, and will analyse the information provided in their sleep diaries. An icon with the name "Sleep diary" appears then at the bottom of the screen that the user can access every day to answer the sleep-related questions (i.e. what time did you go to bed last night?). After

users complete the sleep diary for seven days, the VC conducts another interview (Phase 2). Users learn about their sleep patterns from the previous week and complete the ISI for the second time. Next, the VC delivers the intervention. The intervention includes the provision of general sleep hygiene practices, and also includes evidence-based behavioral recommendations that have been shown to improve insomnia symptoms. KANOPEE features an abbreviated version of CBT-I, highlighting the behavioral component of therapy known as stimulus control (Edinger et al., 2021). For a behavioral treatment to be relevant in general population settings, it must be brief, acceptable to patients, and efficacious over a short time interval, conditions all met by the stimulus control intervention(Buysse et al., 2011). The goals of stimulus control are (1) to remove the association between the bed/bedroom and wakefulness and to promote the association of bed/bedroom with sleep; and (2) to establish a consistent wake-time. Stimulus control instructions include the following: go to bed only when sleepy, get out of bed when unable to sleep, use the bed/bedroom for sleep (no reading, eating, watching TV, etc. in bed) and wake up the same time every morning. Typically, abbreviated behavioral therapy for insomnia also includes sleep restriction(Buysse et al., 2011). However, sleep restriction recommendations were not included in KANOPEE due partly to safety concerns (i.e. it may be contraindicated in certain populations such as those working in high risk occupations, such as heavy machinery operators or drivers, or those predisposed to mania/hypomania, poorly controlled seizure disorders or excessive daytime sleepiness)(Edinger et al., 2021). Furthermore, the most recent guidelines for the use of behavioral and psychological treatments for chronic insomnia recommends that individuals using sleep restriction therapy should be monitored by a clinician during treatment(Edinger et al., 2021). In addition to stimulus control, the intervention includes basic sleep hygiene recommendations, such as, for example, “Do not exercise during the 3–4

hours prior to going to bed" or "Make sure your bedroom is conducive to sleep: dark, quiet, and room temperature is between 18 to 20 Celsius".

The VC provides these sleep recommendations, highlighting the specific ones most useful to the user, based on their sleep diary data and on their answers to the ISI questions on Phase 2. The programme includes an algorithm that serves to highlight the most useful recommendations for a particular user. For instance, if the user reports severe or very severe problems falling asleep, according to his/her answer to the question #1 from the ISI in Phase 2, the programme will highlight the sleep hygiene recommendation "Before going to bed, try exercising abdominal breathing", among others. The VC encourages the user to incorporate these recommendations into their daily routines and to continue completing the sleep diaries for 10 additional days. After these 10 days, users have access to the last screening interview (Phase 3). In this last interview, users are also are asked if they have followed or not each one of the recommendations provided by the VC. After this final interview, users can choose to continue using the app, if they wish (i.e. completing sleep diaries for a longer period of time). If they consider that their sleep problems are persisting, they are prompted to consult a sleep specialist. If the ISI score in this final evaluation is higher than 21 points, the VC suggests contacting a sleep physician. More details about KANOPEE and users' adherence to its sleep recommendations have been reported elsewhere (Dupuy et al., 2022; Philip et al., 2022; Sanchez-Ortuno et al., 2023).

Study outcomes

After downloading the app, users are asked to provide basic sociodemographic variables (age, gender and education level) prior to completing phase 1.

The primary outcome is scores on the ISI(Bastien et al., 2001). The ISI is a 7-item self-report questionnaire that provides a global measure of perceived insomnia severity during the past month.

Scores range from 0-28 and are rated as follows: 0-7 (no insomnia), 8-14 (sub-threshold insomnia), 15-21 (insomnia of moderate severity), and 22-28 (severe insomnia). The ISI was completed at phase 1, phase 2 and phase 3.

Secondary outcomes also completed at phase 1, phase 2 and phase 3 included mental health symptoms, fatigue and sleep diary variables. Mental health symptoms were measured with the PHQ-4(Kroenke et al., 2009), which is an ultra-brief self-report questionnaire including two items assessing depression symptoms and two other items assessing anxiety symptoms. Total scores range from 0 to 12, with higher scores indicating more symptom severity.

Fatigue was evaluated with the FSS(Krupp et al., 1989), a self-report questionnaire including nine items probing the severity of fatigue in different situations during the past week. The total score ranges from 1 to 7.

Sleep diary-derived variables included total time spent in bed (TIB), total sleep time (TST), sleep efficiency (SE) (as calculated from TST/TIB), sleep onset latency (SOL), number of awakenings (NA) and wake time after initial sleep onset (WASO). Sleep diary variables for phase 1 included one night of assessment, whereas sleep diary variables for phase 2 and for phase 3 included mean values for the whole assessment period.

Perceptions of the app's features were quantified with the Acceptability E-Scale (AES) and the ECA-Trust Questionnaire (ETQ), which have shown adequate psychometric properties (Micoulaud-Franchi et al., 2016; Philip et al., 2020; Tariman et al., 2011). The AES comprises six items and provides a total score as well as two sub-scores regarding usability (i.e. perceived ease of using the system) and satisfaction with the system. Examples of items evaluating usability and satisfaction are "How understandable were the questions?" and "How helpful was this programme in describing your symptoms and quality of life?", respectively. Items are answered on a five-

point Likert-type scale ranging from 1: Very unsatisfied, to 5: Very satisfied. The ETQ assesses Trust in the VC with six items that are answered on a four-point Likert-type scale ranging from 0: Not at all, to 3: Totally agree. It provides a total score and sub-scores on two separate dimensions, named perceived credibility and perceived benevolence of the VC. Examples of items evaluating credibility and perceived benevolence of the VC are "Would you agree to being cared for by the virtual agent at home? and "Did you feel that your answers were correctly understood by the virtual agent?", respectively.

At the end of the first screening interview (phase 1), users are asked to complete these measures, but their completion is presented as optional.

Statistical analyses

To test whether the two groups differed on sociodemographic, clinical characteristics, and perceptions of the app's features at phase 1, independent sample t-tests for continuous variables and χ^2 tests for categorical variables were conducted.

A series of binary logistic regression analyses were conducted to ascertain whether perceptions of the app's features predicted treatment completion (yes/no), controlling for insomnia severity at phase 1, and whether this relationship was moderated by age.

mixed effects models . To assess the effect of the intervention between the two groups of users, linear mixed models were estimated for each outcome variables at repeated times (phase 1, phase 2, phase 3). After verification of Akaike criterion, models were fitted with a random intercept and a random slope for the included individuals. No variable transformation was needed in order to complete the models' assumptions. Covariates modelling relied on literature analysis and directed acyclic graphs (DAG). Missing data were considered missing at random (MAR). Obtained coefficients were tested at .05 alpha risk with Wald test.

To test the clinical importance of outcome within the group of subjects completing the intervention, an analysis was conducted on response and remission rates, which were compared across age groups with the Chi-square test. For this analysis, only individuals having baseline ISI scores greater than 8 were included. Following the criteria suggested in the literature(Morin et al., 2009), individuals were considered as treatment responders if their change in ISI score at the end of the intervention compared with baseline was equal to or greater than 7, and as treatment remitters if their phase 3 ISI score was lower than 8.

The alpha risk threshold was set at $\alpha < .05$. Analyses were performed with IBM SPSS version 28.

RESULTS

Participant flow

The participant flowchart can be found in Figure 2. During the study inclusion period (April 2020-Mars 2022), 24774 users downloaded KANOPEE and provided information regarding age, gender and educational level. Among these, 9030 users met the age inclusion criteria (being between 18 and 35 years old or being 65 years or older). A total of 5660 users completed the first treatment phase. Figure 1 provides an overview of all the treatment phases (phases 1 to 3). A total of 289 subjects completed all the study phases and provided scores on phases 1, 2 and 3 on the primary outcome variable, the ISI, (Bastien et al., 2001). A comparison of the percentages of individuals who began treatment (completed phase 1) and continued to use the app until treatment completion (phase 3) showed that the percentage of older adults was statistically significantly higher than the percentage of young users (8% vs 3.5% respectively; $\chi^2=53.18$, $p < .001$). Older individuals who continued using KANOPEE had a higher educational level than those who discontinued the intervention ($p < .05$). Younger and Older users who continued KANOPEE scored higher on

insomnia complaints (ISI score, $p < .05$) and were more likely to report severe sleep complaints than those who discontinued (ISI [15-28], $p < .01$). Younger individuals who continued used the intervention showed a lower level of depression than those who discontinued ($p < .05$). These results are in line with a previous study of ours showing that people with a moderate to severe initial ISI score (≥15) are the ones who tend to use the application the longest (Philip et al. 2022).

Participants' characteristics

Table 1 shows baseline demographic and clinical characteristics of users who completed the first treatment phase (*n*=5660) by age group. Young users were predominantly female with medium to high educational level. By contrast, half of the sample of older users were female and had a lower educational level than young users (both Ps<.001). Regarding clinical status (insomnia severity, depression, anxiety and fatigue symptoms), the young group had statistically significantly worse scores than the older adults. However, an analysis of the sleep diary completed by users regarding their previous night of sleep showed that the older adults displayed worse sleep, such as shorter TST, longer WASO, poorer SE and higher NA during the night (all $p < .05$). However, the young group exhibited longer SOL than older adults ($p < .05$)**.**

Perceptions of the app's features by young and older adults

A total of 1597 users completed the two optional questionnaires designed to evaluate their perceptions of the app's features: acceptance of the app (AES) and trust in the VC (ETQ). We calculated Cronbach's alpha to test the internal consistency of the two questionnaires, as well as the internal consistency of their two subscales, respectively. The Cronbach's alphas for the four subscales and the overall questionnaires ranged from 0.74 to 0.86. These values were considered satisfactory(Bland & Altman, 1997).

The young adults group showed statistically significant higher AES total scores (26.9±3.4 vs 26.2±3.9), as well as higher AES Satisfaction (12.8±2.3 vs 12.5±2.3) and AES Usability scores (14.1±1.5 vs 13.7±1.9) (all $p < .05$). Regarding the ETQ, the young adults group also showed statistically significant higher total scores (19.5±3.2 vs 18.9±3.4), as well as higher ETQ Benevolence (10.3±1.6 vs 10.0±1.5) and ETQ Credibility scores (9.2±2.1 vs 8.9±1.8) (all $p < .01$).

Relationship between perceptions of the app's features and app engagement

A series of logistic regression analyses were conducted using AES and ETQ scores and age group as independent variables, adjusting by insomnia severity scores at phase 1. Treatment completion (yes/no) was the dependent variable. The results showed that neither age group nor total AES scores or subscale scores predicted treatment completion. However, in the two logistic regression analyses using ETQ total scores and ETQ credibility scores, we found a statistically significant interaction with age group (ETQ total scores * age group: OR=1.12, [95%CI=1.01-1.25], $p < .05$ and ETQ credibility scores * age group: OR=1.25, [95%CI=1.06-1.47], $p < .01$. These interactions indicated that, only for the older adults, higher ETQ total scores and higher ETQ credibility scores increased the odds of treatment completion. Such a relationship was not seen in the young adults group. **Comparison of intervention effects across age groups**

Analysis on the primary outcome, ISI scores, showed that average phase 1 scores for both age groups (14.68 ± 5.02 and 13.55 ± 5.48 for the young and older adults, respectively) corresponded to moderate insomnia severity. Younger subjects had a higher average ISI score than older subjects in phase 1 (β=-1.56, CI95%=[-2.07; -1.04]). The mean ISI score decreases less markedly in older subjects than in younger subjects during the intervention (β=0.43, CI95%=[0.04; 0.83]). An analysis of the clinical significance of outcome comparing insomnia remission (ISI scores at phase 3<8) and insomnia response (change of at least 7 points in ISI

score at phase 3) rates across age groups showed that the percentage of subjects attaining remission and treatment response did not differ between the two groups (remission χ^2=2.72, NS; response χ^2=2.34, NS).

Table 2 shows the raw means for secondary outcomes across the three phases, for both groups. Linear mixed effects models revealed a significant Time*Group interaction for the majority of sleep diary variables (TIB, WASO, SE and NA) with higher improvement of these scores over time for older subjects.

DISCUSSION AND IMPLICATIONS

We found that once the fully-automated intervention was initiated (completion of phase 1), the retention rate was higher in older adults. An interesting related finding concerns the perceptions of the app and subsequent usage/engagement with the digital intervention by the older adults. Whereas younger users rated the app's features more positively than older adults, their perceptions were not related to their app engagement. By contrast, perceived credibility of and trust in the VC, the human-like character that delivered the intervention, was related to higher odds of completing the treatment program only in the older adults. A practical implication of these findings is that to optimize older adults' engagement with digital treatment apps like ours, attention should be paid to designing apps whose value and appeal is immediately apparent (Hauk et al., 2018). Since it was the more positive perceptions about the human-like character that predicted treatment completion by the older adults, our results suggest the added value of including virtual humans to help them engage with fully-automated health apps. Bonding experiences with virtual humans have been shown to particularly beneficial for older adults(Straßmann et al., 2020), since their exposure to social stimuli is usually lower than that of

younger subjects. Therefore, as suggested in the literature (Asbjørnsen et al., 2019), the integration of persuasive interaction elements, such as avatars and virtual coaches, could be particularly useful to stimulate older adults' motivation and engagement with fully-automated mhealth interventions. Further studies should consider assessing in better depth users' experiences with VC participating in fully-automated interventions using qualitative methods. The analyses comparing the effects of the intervention in the two groups indicated improvements in the primary outcome variable, insomnia severity, as well as in most of the secondary outcome variables analysed. These sleep variables show more improvement in the older subjects group than in the younger group as the intervention unfolds This is in line with previous reviews of insomnia treatments highlighting that cognitive behavioral therapy for insomnia is effective for younger and older adults(Morin et al., 2006; van Straten et al., 2018). Furthermore, a previous study testing the efficacy of a brief behavioral treatment for insomnia, delivered in two intervention sessions and two telephone calls by a nurse, suggested that an abbreviated behavioral intervention is a feasible and efficacious treatment for older adults, even with comorbid insomnia(Buysse et al., 2011). Therefore, this study suggests that even simpler, briefer and low-cost approaches, such as the one described herein, may also be efficacious for older adults (Lin et al., 2014). We believe that brief interventions with a strong behavioral focus, such as the one described herein, may be perceived more favourably (without the perceived stigma associated with "psychological" treatments) and easy to implement in self-management contexts than interventions including additional cognitive components. There thus appears to be considerable potential for digital self-help behavioral interventions as part of a stepped care model in this population group, in which progressively more intensive therapies could be offered depending on their response to less intensive approaches.

This study has limitations. This was an uncontrolled study, so other factors (e.g., treatment-seeking outside of the study) could explain the improvements found herein. The short-term intervention effects were evaluated only 10 days after the provision of the sleep recommendations (in other abbreviated CBT-I studies treatment effects are typically measured 14 days after the completion of the intervention(Edinger & Sampson, 2003; Okajima et al., 2020), hence we acknowledge that greater long-term follow-up would be necessary to document sustained intervention effects. The self-selected sample restricts the generalisability of the results to broader samples of older adults. Furthermore, comorbidities that could impact insomnia symptoms and response to the intervention (e.g. sleep apnea, depression) were not assessed in our study sample. This app was designed to be used by the general population and did not take into account the specific needs and obstacles that older adults might encounter when using it. Involvement of end users throughout the development of the intervention has been shown to facilitate engagement with technology-based interventions, particularly in older people (Wildenbos et al., 2018). Finally, concerning age-related differences and improvement between intervention phases, the effect sizes in our study are small to medium. Future studies with an even larger population will need to be carried out.

To summarize, our data shows that a smartphone-based brief behavioral intervention, delivered with the help of a VC, is associated with an improvement of insomnia symptoms and related daytime impairment (fatigue, mental health symptoms) in older adults. It also suggests that integrating persuasive interaction elements, such as avatars and virtual coaches, could be particularly useful to stimulate older adults' engagement with this type of interventions. A randomized trial of KANOPEE with older adults is warranted.

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CONFLICT OF INTEREST

None reported.

DATA AVAILABILITY

The study was registered at ClinicalTrials.gov (#NCT05074901). The data supporting the findings of this study are available from the corresponding author upon reasonable request due to privacy and other restrictions.

REFERENCES

Asbjørnsen, R. A., Smedsrød, M. L., Solberg Nes, L., Wentzel, J., Varsi, C., Hjelmesæth, J., & van Gemert-Pijnen, J. E. (2019). Persuasive System Design Principles and Behavior Change Techniques to Stimulate Motivation and Adherence in Electronic Health Interventions to Support Weight Loss Maintenance: Scoping Review. *Journal of Medical Internet Research*, *21*(6), e14265. https://doi.org/10.2196/14265

Askari, M., Klaver, N. S., van Gestel, T. J., & van de Klundert, J. (2020). Intention to use Medical Apps Among Older Adults in the Netherlands: Cross-Sectional Study. *Journal of Medical Internet Research*, *22*(9), e18080. https://doi.org/10.2196/18080

Bakken, M. S., Engeland, A., Engesæter, L. B., Ranhoff, A. H., Hunskaar, S., & Ruths, S. (2014). Risk of hip fracture among older people using anxiolytic and hypnotic drugs: a nationwide prospective cohort study. *European Journal of Clinical Pharmacoly*, *70*(7), 873-880. https://doi.org/10.1007/s00228-014-1684-z

Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Medicine*, *2*(4), 297-307. https://doi.org/S1389945700000654 [pii]

Berry, S. D., Lee, Y., Cai, S., & Dore, D. D. (2013). Nonbenzodiazepine sleep medication use and hip fractures in nursing home residents. *JAMA Internal Medicine*, *173*(9), 754-761. https://doi.org/10.1001/jamainternmed.2013.3795

Bland, J. M., & Altman, D. G. (1997). Cronbach's alpha. *British Medical Journal*, *314*(7080), 572. https://doi.org/10.1136/bmj.314.7080.572

Bloom, H. G., Ahmed, I., Alessi, C. A., Ancoli-Israel, S., Buysse, D. J., Kryger, M. H., Phillips, B.A., Thorpy, M.J., Vitiello, M.V., &Zee, P. C. (2009). Evidence-based recommendations for the assessment and management of sleep disorders in older persons. Journal of the American Geriatrics Society, 57(5), 761-789. https://doi.org/10.1111/j.1532-5415.2009.02220.x

Boucher, E., Honomichl, R., Ward, H., Powell, T., Stoeckl, S. E., & Parks, A. (2022). The Effects of a Digital Well-being Intervention on Older Adults: Retrospective Analysis of Real-world User Data. *Journal of Medical Internet Research Aging*, *5*(3), e39851. https://doi.org/10.2196/39851

Buysse, D. J., Germain, A., Moul, D. E., Franzen, P. L., Brar, L. K., Fletcher, M. E., Begley, A., Houck, P. R., Mazumdar, S., Reynolds, C.F.3rd &Monk, T. H. (2011). Efficacy of Brief Behavioral Treatment for Chronic Insomnia in Older Adults. *Archives of Internal Medicine*. https://doi.org/archinternmed.2010.535 [pii] 10.1001/archinternmed.2010.535

Chen, T. Y., Lee, S., & Buxton, O. M. (2017). A Greater Extent of Insomnia Symptoms and Physician-Recommended Sleep Medication Use Predict Fall Risk in Community-Dwelling Older Adults. S*leep, 40(*11). https://doi.org/10.1093/sleep/zsx142 4159943 [pii]

Chen, Y., Lu, T., Ku, E., Chen, C., Fang, C., Lai, P., & Liu, C. (2023). Efficacy of brief behavioural therapy for insomnia in older adults with chronic insomnia: a systematic review and meta-analysis from randomised trials [Review]. A*ge and Ageing, 52(*1), Article ARTN afac333. https://doi.org/10.1093/ageing/afac333

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., Rogers, W. A., & Sharit, J. (2006). Factors predicting the use of technology: findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). P*sychology and Aging, 21(*2), 333-352. https://doi.org/10.1037/0882-7974.21.2.333

Doghramji, K. (2006). The epidemiology and diagnosis of insomnia. *American Journal of Managed Care , 12(*8 Suppl), S214-220.

Drerup, M. L., & Ahmed-Jauregui, S. (2019). Online Delivery of Cognitive Behavioral Therapy-Insomnia: Considerations and Controversies. *Sleep Medicine Clinics, 14(*2), 283-290. https://doi.org/10.1016/j.jsmc.2019.02.001

Dupuy, L., Morin, C. M., de Sevin, E., Taillard, J., Salles, N., Bioulac, S., Auriacombe, M., Micolaud-Franchi, J. A. & Philip, P. (2022). Smartphone-based virtual agents and insomnia management: A proof-of-concept study for new methods of autonomous screening and management of insomnia symptoms in the general population. Journal of *Sleep Research, 31(*2), e13489. https://doi.org/10.1111/jsr.13489

Edinger, J., Arnedt, J., Bertisch, S., Carney, C., Harrington, J., Lichstein, K., Sateia, M. J., Troxel, W. M., Zhou, E. S., Kazmi, U., Heald, J..L. &Martin, J. (2021). Behavioral and psychological treatments for chronic insomnia disorder in adults: an American Academy of Sleep Medicine clinical practice guideline. J*ournal of Clinical Sleep Medicine, 17(*2), 255-262. https://doi.org/10.5664/jcsm.8986

Edinger, J. D., & Sampson, W. S. (2003). A primary care "friendly" cognitive behavioral insomnia therapy. S*leep, 26(*2), 177-182. https://doi.org/10.1093/sleep/26.2.177

Espie, C. A. (2009). "Stepped care": a health technology solution for delivering cognitive behavioral therapy as a first line insomnia treatment. S*leep, 32(*12), 1549-1558. https://doi.org/10.1093/sleep/32.12.1549.

Gebara, M. A., & Karp, J. F. (2020). Sleep disturbances are among the risk factors associated with cognitive impairment. I*nternational Psychogeriatrics, 32(*7), 791-792. https://doi.org/10.1017/S1041610219001868

Goodarzi, Z., Holroyd-Leduc, J., Seitz, D., Ismail, Z., Kirkham, J., Wu, P., Fox, L., Hykaway, W., Grossman L., Ewa, V., Veroniki, A. A., Tricco, A. C., Straus, S. & Watt, J. (2023). Efficacy of virtual interventions for reducing symptoms of depression in community-dwelling older adults: a systematic review. I*nternational Psychogeriatrics, 35(*3), 131-141. https://doi.org/10.1017/S1041610222000412

Gulliford, M., & Alageel, S. (2019). Digital health intervention at older ages. L*ancet Digital Health, 1(*8), e382-e383. https://doi.org/S2589-7500(19)30194-3 [pii] 10.1016/S2589-7500(19)30194-3

Hauk, N., Huffmeier, J., & Krumm, S. (2018). Ready to be a Silver Surfer? A Meta-analysis on the Relationship Between Chronological Age and Technology Acceptance . C*omputers in Human Behavior, 84,* 304-319. https://doi.org/10.1016/j.chb.2018.01.020

Hultsch, D. F., Hammer, M., & Small, B. J. (1993). Age differences in cognitive performance in later life: relationships to self-reported health and activity life style. Journal of *Gerontology, 48(*1), P1-11. https://doi.org/10.1093/geronj/48.1.p1

Koffel, E., Bramoweth, A. D., & Ulmer, C. S. (2018). Increasing access to and utilization of cognitive behavioral therapy for insomnia (CBT-I): a narrative review. *Journal* of *General Internal Medicine, 33(*6), 955-962. https://doi.org/10.1007/s11606-018-4390-1

Kroenke, K., Spitzer, R. L., Williams, J. B., & Löwe, B. (2009). An ultra-brief screening scale for anxiety and depression: the PHQ-4. P*sychosomatics, 50(*6), 613-621. https://doi.org/10.1176/appi.psy.50.6.613

Krupp, L. B., Larocca, N. G., Muirnash, J., & Steinberg, A. D. (1989). The Fatigue Severity Scale - Application to patients with multiple-sclerosis and systemic lupus erythematosus. A*rchives of Neurology, 46(*10), 1121-1123.

Lin, F. Y., Chen, P. C., Liao, C. H., Hsieh, Y. W., & Sung, F. C. (2014). Retrospective population cohort study on hip fracture risk associated with zolpidem medication. S*leep, 37(*4), 673-679. https://doi.org/10.5665/sleep.3566

Melenhorst, A., Rogers, W., & Bouwhuis, D. (2006). Older adults' motivated choice for technological innovation: Evidence for benefit-driven selectivity. P*sychology and Aging, 21(*1), 190-195. https://doi.org/10.1037/0882-7974.21.1.190

Micoulaud-Franchi, J. A., Sauteraud, A., Olive, J., Sagaspe, P., Bioulac, S., & Philip, P. (2016). Validation of the French version of the Acceptability E-scale (AES) for mental E-health systems. P*sychiatry Research, 237,* 196-200. https://doi.org/10.1016/j.psychres.2016.01.043

Mitzner, T., Boron, J., Fausset, C., Adams, A., Charness, N., Czaja, S., Dijkstra, K., Fisk, A.D., Rogers, W. A.&Sharit, J. (2010). Older adults talk technology: Technology usage and attitudes. C*omputers in Human Behavior, 26(*6), 1710-1721. https://doi.org/10.1016/j.chb.2010.06.020

Morin, C., Vallières, A., Guay, B., Ivers, H., Savard, J., Mérette, C., Bastien, C. &Baillargeon, L. (2009). Cognitive behavioral therapy, singly and combined with medication, for persistent insomnia: a randomized controlled trial. J*AMA, 301(*19), 2005-2015. https://doi.org/301/19/2005 [pii] 10.1001/jama.2009.682

Morin, C. M., Bootzin, R. R., Buysse, D. J., Edinger, J. D., Espie, C. A., & Lichstein, K. L. (2006). Psychological and behavioral treatment of insomnia:update of the recent evidence (1998-2004). S*leep, 29(1*1), 1398-1414.

Newman, M. G., Erickson, T., Przeworski, A., & Dzus, E. (2003). Self-help and minimal-contact therapies for anxiety disorders: Is human contact necessary for therapeutic efficacy? Journal of *Clinical Psychology,* 5*9(3*), 251-274. https://doi.org/10.1002/jclp.10128

Okajima, I., Akitomi, J., Kajiyama, I., Ishii, M., Murakami, H., & Yamaguchi, M. (2020). Effects of a Tailored Brief Behavioral Therapy Application on Insomnia Severity and Social Disabilities Among Workers With Insomnia in Japan: A Randomized Clinical Trial. JA*MA Network Open,* 3*(4*), e202775. https://doi.org/10.1001/jamanetworkopen.2020.2775

Patel, D., Steinberg, J., & Patel, P. (2018). Insomnia in the Elderly: A Review. Journal of *Clinical Sleep Medicine,* 1*4(6*), 1017-1024. https://doi.org/10.5664/jcsm.7172

Philip, P., Dupuy, L., Auriacombe, M., Serre, F., de Sevin, E., Sauteraud, A., & Micoulaud-Franchi, J. A. (2020). Trust and acceptance of a virtual psychiatric interview between embodied conversational agents and outpatients. NP*J DigitalMedicine,* 3*,* 2. https://doi.org/10.1038/s41746-019-0213-y

Philip, P., Dupuy, L., Sagaspe, P., de Sevin, E., Auriacombe, M., Taillard, J., Micoulaud-Franchi, J. A., &Morin, C. M. (2022). Efficacy of a Smartphone-Based Virtual Companion to Treat Insomniac Complaints in the General Population: Sleep Diary Monitoring Versus an Internet Autonomous Intervention. *Journal* of *Clinical Medicine,* 1*1(1*5). https://doi.org/10.3390/jcm11154387

Riemann, D., Benz, F., Dressle, R. J., Espie, C. A., Johann, A. F., Blanken, T. F.,Leerssen, J., Wassing, R., Henry, A. L., Kyle, S.D., Spiegelhalder, K. &Van Someren, E. J. W. (2022). Insomnia disorder: State of the science and challenges for the future. *Journal of Sleep Research,* 3*1(4*), e13604. https://doi.org/10.1111/jsr.13604

Riemann, D., Krone, L. B., Wulff, K., & Nissen, C. (2020). Sleep, insomnia, and depression. N*europsychopharmacology, 45(1*), 74-89. https://doi.org/10.1038/s41386-019-0411-y

Robbins, R., Sonnega, A., Turner, R. W., Jean-Louis, G., Butler, M., Osorio, R. S., & Langa, K. M. (2020). Sleep Difficulties and Cognition for 10 Years in a National Sample of U.S. Older Adults. *Innovation in Aging,* 4*(4*), igaa025. https://doi.org/10.1093/geroni/igaa025

Sadler, P., McLaren, S., & Jenkins, M. (2013). A psychological pathway from insomnia to depression among older adults. *International Psychogeriatrics, 25(8*), 1375-1383. https://doi.org/10.1017/S1041610213000616

Sanchez-Ortuno, M., Pecune, F., Coelho, J., Micoulaud-Franchi, J., Salles, N., Auriacombe, M., Serre, F., Levavasseur, Y., De Sevin, E., Sagaspe, P. &Philip, P. (2023). Predictors of users' adherence to a fully automated digital intervention to manage insomnia complaints. J*ournal of the American Medical Informatics Association.* https://doi.org/10.1093/jamia/ocad163

Straßmann, C., Krämer, N. C., Buschmeier, H., & Kopp, S. (2020). Age-Related Differences in the Evaluation of a Virtual Health Agent's Appearance and Embodiment in a Health-Related Interaction: Experimental Lab Study. Journal of *Medical Internet Research, 22(4)*, e13726. https://doi.org/10.2196/13726

Tariman, J. D., Berry, D. L., Halpenny, B., Wolpin, S., & Schepp, K. (2011). Validation and testing of the Acceptability E-scale for web-based patient-reported outcomes in cancer care. Ap*plied Nursing Research, 24(1)*, 53-58. https://doi.org/10.1016/j.apnr.2009.04.003

Vailati Riboni, F., Sadowski, I., Comazzi, B., & Pagnini, F. (2022). Mindful Age and Technology: a Qualitative Analysis of a Tablet/Smartphone App Intervention Designed for Older Adults. *Integrative Psychological and Behavioral Scienc*e *, 5**6(3***), 739-754. https://doi.org/10.1007/s12124-020-09580-x

van Acker, J., Maenhout, L., & Compernolle, S. (2023). Older Adults' User Engagement With Mobile Health: A Systematic Review of Qualitative and Mixed-Methods Studies. *Innoation in Aging,* 7*(2*), igad007. https://doi.org/10.1093/geroni/igad007

van Hooren, S. A., Valentijn, A. M., Bosma, H., Ponds, R. W., van Boxtel, M. P., & Jolles, J. (2007). Cognitive functioning in healthy older adults aged 64-81: a cohort study into the effects of age, sex, and education.*Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition ,* 1*4(1*), 40-54. https://doi.org/10.1080/138255890969483

van Straten, A., van der Zweerde, T., Kleiboer, A., Cuijpers, P., Morin, C. M., & Lancee, J. (2018). Cognitive and behavioral therapies in the treatment of insomnia: A meta-analysis. Sl*eep Medicine Reviews, 3**8,* 3-16. https://doi.org/S1087-0792(17)30034-5 [pii] 10.1016/j.smrv.2017.02.001

Vincent, N., & Walsh, K. (2013). Stepped Care for Insomnia: an Evaluation of Implementation in Routine Practice [Article]. Jo*urnal of Clinical Sleep Medicine,* 9*(3*), 227-234. https://doi.org/10.5664/jcsm.2484

Wildenbos, G. A., Peute, L., & Jaspers, M. (2018). Aging barriers influencing mobile health usability for older adults: A literature based framework (MOLD-US). In*ternational Journal of Medical Informatics, 114,* 66-75. https://doi.org/S1386-5056(18)30245-4 [pii] 10.1016/j.ijmedinf.2018.03.012

Wong, A. K. C., Wong, F. K. Y., Chow, K. K. S., Wong, S. M., Bayuo, J., & Ho, A. K. Y. (2022). Effect of a Mobile Health Application With Nurse Support on Quality of Life Among Community-Dwelling Older Adults in Hong Kong: A Randomized Clinical Trial. JA*MA Network Open,* 5*(11*), e2241137. https://doi.org/10.1001/jamanetworkopen.2022.41137

Wuthrich, V. M., & Frei, J. (2015). Barriers to treatment for older adults seeking psychological therapy. *International Psychogeriatrics, 27(7*), 1227-1236. https://doi.org/10.1017/S1041610215000241

Table 1. Socio-demographic, clinical and sleep diary variables of participants completing the first screening interview, phase 1 (*n*=5,660), by age group

Variable	Young adults	Older adults	*p*-value	Cohen's d
Sociodemographic variables	*n*=3,692	*n*=1,968		
Age (years), Mean±SD	27.4 ± 5.0	70.5 ± 4.9	<.001	-8.615
Gender, *n* (%)				
Female	2,630 (71.2)	1,007 (51.2)	<.001	
Educational level, *n* (%)			<.001	
Middle school	350 (9.5)	521 (26.5)		
High school	631 (17.1)	405 (20.6)		
Less than 5 years of university	2,249 (60.9)	735 (37.3)		
More than 5 years of university	462 (12.5)	307 (15.6)		
Clinical variables				
ISI score, Mean±SD	14.7 ± 5.0	13.5 ± 5.5	<.001	0.217
PHQ-4 score, Mean±SD	6.1 ± 3.2	4.8 ± 3.5	<.001	0.375
Anxiety subscore	3.6 ± 1.8	2.8 ± 2.0	<.001	0.398
Depression subscore	2.5 ± 1.8	2.0 ± 1.8	<.001	0.270
FSS score, Mean±SD	4.8 ± 1.2	4.0 ± 1.6	<.001	0.631
Sleep diary variables (night 1)	*n*=3,194	*n*=1,857		
Time in bed (hours), Mean±SD	8.94 (1.89)	8.93 (1.80)	.47	0.002
Total sleep time (hours), Mean±SD	6.46 (2.49)	5.08 (2.95)	<.001	0.517
Sleep onset latency (hours), Mean±SD	0.90 (1.25)	0.82 (1.28)	<.05	0.063
Wake after sleep onset (hours), Mean±SD	0.84 (1.71)	1.62 (2.08)	<.001	-0.424
Sleep efficiency, Mean±SD	0.73 (0.25)	0.56 (0.31)	<.001	0.582
Number of awakenings, Mean±SD	1.56 (1.42)	2.00 (1.41)	<.001	-0.314

Notes. ISI = Insomnia Severity Index; PHQ-4 = Patient Health Questionnaire; FSS = Fatigue Severity Scale.

Table 2. Effects on insomnia, mental health, fatigue symptoms and sleep diary variables[a] using linear mixed effects models

Variable	Group (réf = Young)	Phase 1 Mean±SD	Phase 2 Mean±SD	Phase 3 Mean±SD	Intercept γ (CI)	Group β (CI)	Time x Group β (CI)
ISI scores	Older adults	13.55 (5.48)	12.52 (5.49)	11.38 (5.33)	16.67 (16.34; 17.00)**	-1.56 (-2.07; -1.04)**	0.43 (0.04; 0.83)**
	Young adults	14.68 (5.02)	13.33 (5.55)	11.66 (5.72)			
PHQ-4 scores	Older adults	4.83 (3.51)	4.17 (3.26)	3.59 (2.93)	6.74 (6.52; 6.97)**	-1.36 (-1.0; -1.04)**	0.12 (-0.11; 0.35)
	Young adults	6.09 (3.24)	5.16 (3.28)	4.30 (3.06)			
FSS scores	Older adults	3.97 (1.56)	3.88 (1.46)	3.49 (1.45)	5.10 (5.00; 5.20)**	-0.91 (-1.05; -0.77)**	0.07 (-0.04; 0.18)
	Young adults	4.82 (1.18)	4.43 (1.32)	4.18 (1.32)			
TIB (Hours)	Older adults	8.94 (1.81)	8.60 (1.06)	8.49 (0.83)	8.94 (8.84; 9.05)**	0.11 (-0.06; 0.27)	-0.11(-0.23; -0.01)*
	Young adults	8.94 (1.89)	9.00 (1.11)	8.79 (0.88)			
TST (Hours)	Older adults	5.08 (2.95)	5.87 (1.35)	6.20 (1.03)	6.06 (5.91; 6.21)**	-1.50 (-1.74; -1.27)**	0.13 (-0.03; 0.28)
	Young adults	6.46 (2.49)	6.97 (1.19)	7.18 (0.89)			
SOL (Hours)	Older adults	0.83 (1.28)	0.70 (0.58)	0.61 (0.55)	1.08 (0.99; 1.16)**	-0.11 (-0.24; 0.02)	0.03 (-0.06; 0.12)
	Young adults	0.91 (1.25)	0.84 (0.71)	0.68 (0.53)			
WASO (Hours)	Older adults	1.63 (2.08)	1.01 (0.82)	0.82 (0.59)	0.97 (0.86; 1.07)**	0.91 (0.74; 1.07)**	-0.13 (-0.23; -0.02)*
	Young adults	0.84 (1.72)	0.55 (0.61)	0.41 (0.42)			
Sleep Efficiency	Older adults	0.57 (0.31)	0.69 (0.15)	0.74 (0.12)	0.69 (0.67; 0.70)**	-0.18 (-0.21; -0.16)**	0.03 (0.01; 0.04)**
	Young adults	0.73 (0.25)	0.78 (0.13)	0.82 (0.09)			
Number of Awakenings	Older adults	2.00 (1.41)	1.61 (0.91)	1.41 (0.86)	1.67 (1.59; 1.75)**	0.56 (0.44; 0.67)**	-0.12 (-0.21; -0.04)**
	Young adults	1.56 (1.42)	1.40 (0.97)	1.09 (0.80)			

Notes. ISI: Insomnia Severity Index; PHQ-4: Patient Health Questionnaire; FSS: Fatigue Severity Scale; TIB: Time in Bed; TST: Total Sleep Time; SOL: Sleep Onset Latency; WASO: Wake time After Sleep Onset.

[a] For sleep diary variables, Phase 1 values correspond to night 1 of assessment. Phase 2 values are mean values of first week of assessment (minus night 1). Phase 3 values are mean values of 10 nights of assessment after provision of sleep-related recommendations.

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

Figures

Figure 1. Overview of phases of the Kanopee digital intervention.

Note. (A) screenshot of Louise questioning the Insomnia Severity Index (ISI); (B) screenshot of sleep diary; (C) screenshot of a sleep recommendation given by Louise during Phase 2; (D) screenshot of visual feedback provided by the app on the completion of each day of sleep diary.

Alt Text: Cell phone screenshots displaying the virtual companion, sleep diary questions to respond, a sleep-related recommendation and a graphic summary of sleep diary data. Below, arrows showing the programme phases.

Figure 2. Flow of participants.

Alt Text: Chart showing the number of young and older adults downloading the app, completing phase 1, completing measures of app perceptions and completing the three study phases.

Figure 1

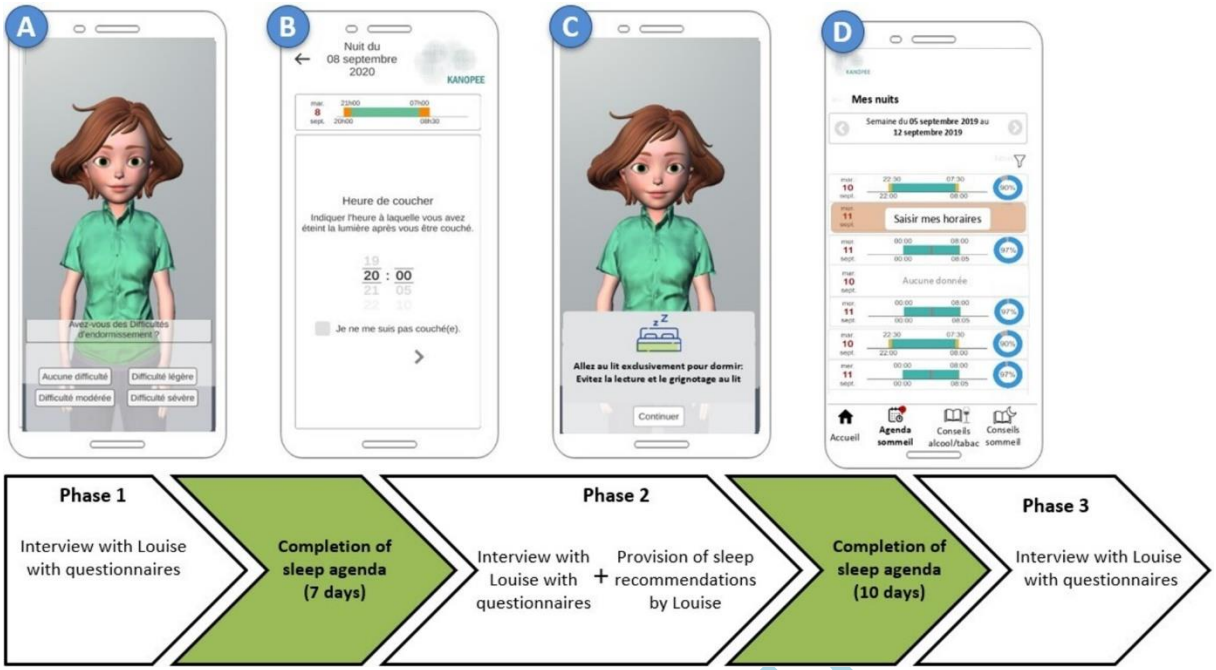

Figure 2