



Use of the Xiaomi Mi Band for sleep monitoring and its influence on the daily life of older people living in a nursing home

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Abstract

Background: Lower quantity and poorer sleep quality are common in most older adults, especially for those who live in a nursing home. The use of wearable devices, which measure some parameters such as the sleep stages, could help to determine the influence of sleep quality in daily activity among nursing home residents. Therefore, this study aims to analyse the influence of sleep and its changes concerning the health status and daily activity of older people who lived in a nursing home, by monitoring the participants for a year with Xiaomi Mi Band 2. **Methods:** This is a longitudinal study set in a nursing home in [Details omitted for double-anonymized peer reviewed]. The Xiaomi Mi Band 2 will be used to measure biomedical parameters and different assessment tools will be administered to participants for evaluating their quality of life, sleep quality, cognitive state, and daily functioning. **Results:** A total of 21 nursing home residents participated in the study, with a mean age of 86.38 ± 9.26 . The main outcomes were that sleep may influence daily activity, cognitive state, quality of life, and level of dependence in activities of daily life. Moreover, environmental factors and the passage of time could also impact sleep. **Conclusions:** Xiaomi Mi Band 2 could be an objective tool to assess the sleep of older adults and know its impact on some factors related to health status and quality of life of older nursing homes residents. **Trial Registration:** NCT04592796 (Registered 16 October 2020) Available on: <https://clinicaltrials.gov/ct2/show/NCT04592796>.

Keywords

Sleep, aging, participatory health, quality of life, activities of daily life, occupational therapy, wearable technology, xiaomi mi smart band 2

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Introduction

Sleep is considered an occupation that performs a vital role in people's health and well-being.¹ As people age, the duration and quality of sleep are negatively influenced by alterations in its sleep-wake cycle, with less restful deep sleep and sleep stages fragmented by increased nocturnal awakenings.^{2,3} Likewise, changes associated with the passage of time, such as changes in roles, environment, or healthy lifestyle habits, affect sleep status.^{4,5} In the aging stage, sleep problems are often underdiagnosed, and their prevalence depends on social and environmental factors and daily habits and routines.^{2,6} Globally, it is estimated that 40%–60% of the older population has poor sleep

quality and sleep difficulties.⁷ Therefore, sleep problems have become a problem associated with the growing aging phenomenon,^{8,9} and a relevant public health problem, mainly affecting older people's quality of life.^{7,8}

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Sleep problems can be a risk factor for the development of cardiovascular diseases or diabetes, digestive diseases, and respiratory diseases.¹⁰ Also, insufficiency of restful sleep and its poor quality is associated with a higher prevalence of cognitive impairment,³ mental disorders (specifically depression, anxiety, or fatigue),^{4,11} risk of falling,¹² and decreased daily functioning¹³ and physical activity.^{6,12} Specifically, the presence of sleep disorders and their relation to different diseases or alterations in the health of older adults can have a significant impact on their occupational performance,¹ such as in the development of daily routines or their participation in society.^{1,14} In most cases, older adults present difficulties in their daily living, requiring third-party care, such as family members or other caregivers,¹⁵ greater attention and frequency of health resources, and a greater need of institutional resources, like nursing homes, for older adults.^{8,15}

Nursing homes tend to be the most frequented and required resources for the older population in need of some sort of assistance.^{13,16} These resources are increasingly in demand in countries with high rates of older adults, such as Spain, where 81.5% of the older people live in nursing home.¹⁶ Residents of these resources are exposed to changes in the environment and routines, lack of social participation, more time in bed, and are poorly exposed to the sun, which can cause the increase or appearance of sleep disorders and associated factors.^{4,17} It is estimated that 65% of nursing home residents can have sleep problems.¹⁷ Some studies report that older people in nursing homes have excessive daytime sleepiness, disturbed nighttime sleep, and high levels of sedentary lifestyle.^{13,18} Martins da Silva et al.¹⁴ refer that older institutionalized with poor sleep quality have low levels of activity and social participation, difficulties in carrying out leisure activities, and need support for performing their activities of daily living (ADLs).

Due to this situation and the increased prevalence of sleep problems in the older population, it is required the development of strategies for planning the care and services that nursing home residents need.¹⁹ As well as, for health professionals to work in an interdisciplinary way to improve the quality of sleep and its influence on the daily life of the older population.¹⁹

Therefore, some studies report that the development of longitudinal studies about different geriatric syndromes is necessary to explore the impact of disorders such as sleep disturbances on the quality of life of older adults.^{20,21} The development of these studies combining objective and subjective measurements can provide health professionals and governmental agents with the necessary information to promote organizational and environmental changes and development interventions in nursing homes to improve their sleep quality and quality of life.²² Therefore, in contrast to previous studies, this study intends to analyse the quality and quantity of sleep and its influence, using subjective and objective measures.

The most common subjective measures are assessment tools.²¹ Regarding objective measurements, there are a variety of instruments that analyse the quality and quantity of sleep. The clinical tool used to detect possible sleep difficulties is polysomnography (PSG).²³ PSG, considered the 'Gold Standard,' is the most reliable sleep test available and the most used in sleep units.²³ However, its cost and invasiveness have led to the use of other devices such as actigraphy, which is scientifically recognized as an objective instrument to study sleep.²⁴ So, some studies focussed on sleep measurement use actigraphy.^{24,25} But with time, new devices that are handy to society have been emerging and appearing on the market, such as wearable devices.²⁴ Today, these devices are used by the majority of the population, and there is evidence in the literature of previous works that have used them to evaluate mainly physical activity.^{26,27}

Some studies report that wearable devices can promote healthy lifestyle habits and help people to be more aware of their health status, specifically the activity they perform and the quality of their sleep.^{20,28} In addition, the remote monitoring of people in their daily environment is highlighted as a positive point in these devices, providing crucial information about people's health to health care professionals.^{20,28,29} Likewise, the study performed by Chong et al.²⁸ refers that wearable devices are helpful tools that stand out for four aspects: the discretion of the device, the motivation they provide, responsibility, and sleep hygiene. Kondama Reddy et al.²⁷ refers that it would be interesting to know the impact of these devices on the population in the long term. However, no study has used wearable devices in the long term in a specific population.

Many wearable devices have validation studies, comparing them with PSG, and many others are in process, with previous results showing similarity of the data from these devices with PSG.^{24,30,31} Within the variety of wearable devices, the Xiaomi Mi Band devices are one of the most attractive to the public due to their quality-price ratio.³² Some research has used this device to measure the health status of different populations. Both Miranda-Duro et al.¹² and Domingo et al.³³ focussed on investigating the risk of falling and physical activity in older people using the Xiaomi Mi Band 2. Queirós et al.³⁴ focussed on studying the impact of stress in the work environment using the Xiaomi Mi Band 3. However, none of them researched sleep as the main variable and its influence on the daily life of the population.

Thus, the main objective of this study was to analyse the influence of sleep and its changes concerning the health status and daily activity of older people who lived in a nursing home, by monitoring the participants for a year with Xiaomi Mi Band 2. Specifically, (I) we analysed the sleep and activity performed by older residents and the influence of falls on these parameters; (II) we studied the association between sleep and its related variables (light, deep sleep, and wake after sleep onset (WASO)) with the

quality of life, independence in ADLs, cognitive status, risk of falling, and perception of sleep; (III) we analysed whether different environmental factors (temperature, rain, hours of sun, and humidity) influenced the sleep and activity performed by the older adults; lastly, (IV) we researched if there were some changes in the daily functioning and health status of the participants throughout the study, based on the data associated with the assessment tools and the sleep and activity data provided by the Xiaomi Mi Band 2.

Methods

Research design

A longitudinal study was conducted among older people residing as nursing home residents or attending the day centre in Galicia (Spain). The population's characteristics, specifically the daily activity and sleep quality, were registered and monitored for 1 year, beginning in December 2018 and ending in December 2019.

Before starting the study, all participants gave their informed consent to participate. Also, the study protocol was approved by the A Coruña-Ferrol Research Ethics Committee (code:2018/473), and it was registered in the Clinical Trials Protocol Registration and Results System (NCT04592796). In addition, the study was conducted following the Helsinki Statement for human research ethics and European Convention on Human Rights and Biomedicine. The researchers maintained the confidentiality of all data collected and the anonymity of each participant. Thus, the Spanish 2016/679 and European Organic 95/46/E.C. Law on the protection of personal data was respected at all times.^{35,36}

Participants

All residents of the nursing home ($n = 44$) were considered for participating in the study. The selection was performed through an intentional sample based on inclusion and exclusion criteria. The participants' inclusion criteria were: (a) to be at least 65 years old, (b) to be a user of the residence or day centre where the study was performed, (c) to wear the wristband day and night. Whereas the participants' exclusion criteria were (a) to present a moderate or very severe cognitive impairment, (b) to be in a situation of legal incapacity, (c) to be in a situation of request to be transferred to another centre. Thus, from a total of 44 nursing home residents, only 21 older adults met the inclusion criteria. Characteristics of including participants are shown in Table 1.

Procedure

Before the data collection phase, the informed consent was signed by the responsible researcher and the person participating in the study.

Table 1. Characteristics of participants

Characteristics	N (%) / mean \pm SD
Women	17 (81%)
Age (years)	86.38 \pm 9.26
BMI (Kg/m ²)	24.97 \pm 4.59
Widowed	19 (90.5%)
Nursing-home residents	18 (85.7%)
Cognitive status ^a	
No cognitive decline	3 (14.30%)
Very mild cognitive decline	8 (38.1%)
Mild cognitive impairment	10 (47.6%)
Health diagnosis	
Hypertension (I10) ^{*b}	14 (66.7%)
Osteoporosis (M80-82) ^b	14 (66.7%)
Medication	
Number	6.67 \pm 2.35
Corticosteroids	15 (71.4)

Lobo MEC: Lobo mini-cognitive examination; ICD-10: International Classification of Diseases and Related Health Problems; GDS: Global Deterioration Scale.

^aCognitive status was obtained by Lobo MEC and classified by Reisberg GDS.

^bHealth conditions were grouped and classified into different types following the ICD-10.

Following the informed consent process, five assessment tools were administered at baseline and the end of the study. During this assessment process, participants completed the EuroQol 5D-5L (EQ 5D-5L)³⁷ and Pittsburgh Sleep Quality Index (PSQI)^{6,38,39} under the assistance and supervision of the researchers. Likewise, the researchers filled out Lobo mini-cognitive examination (MCE),^{40,41} Barthel ADL Index⁴² and Tinetti scale.⁴³ In addition, at the project's beginning, some sociodemographic characteristics of each participant were consulted in the nursing home database.

Once the initial assessment was completed and a wristband had been given to each participant, it was explained the use of the Xiaomi Mi Band 2 and the importance of wearing it until the end of the study. Participants did not have the obligation of interacting with the device if they did not want to. Data synchronization and charging of the wristbands were carried out by the research team during the study.

At the end of the research, the researchers want to determine the satisfaction on the project and the wristbands' use. For that, the participants filled out a final questionnaire with the support of the research team. In addition, data associated with the risk of falling, hospital stay, daily living aids, and environmental data from nursing home settings were recorded by the research group throughout the study.

Measures

Data from all measures were collected in Microsoft Excel and organized according to sociodemographic data, assessment tools, Xiaomi activity and sleep data, environmental data, and fall history. This information on participants was published previously anonymized in a dataset⁴⁴.

Xiaomi mi Band2. All participants used the Xiaomi Mi Band 2 based on other studies.^{12,45} The choice of this wearable was based on its ease of use and cost³² Previous studies consider that this wristband reliably measures the number of steps, distance, and duration of sleep, classifying light sleep, deep sleep, and awake time.^{25,31} The classification total sleep time (TST) data was based on the National Sleep Foundation's sleep duration recommendations: 7–8 'hours optimal'; 5–6 'less optimal sleep duration'; less than 5 h 'inadequate sleep duration'; more than 9 h 'excessive sleep duration'.⁴⁶ The classification of the steps followed the following recommendations: >3000 steps/day 'low level of physical activity'; 3000–8000 steps/days 'moderate physical activity'; <8000 steps/day 'intense level of physical activity'.⁴⁷

MeteoGalicia platform. Some environmental factors were recorded using a meteorological station near the nursing home under study. The meteorological device is from the Meteorological Observation and Prediction Unit of Xunta de Galicia. It aims to predict the weather in Galicia throughout the record of environmental factors such as temperature, rain, sun hours, wind, or atmospheric pressure. Based on scientific evidence on environmental factors and their influence on the quality of life or quality of sleep,^{48,49} the research group focussed on temperature, rainfall, humidity and sun hours data.

Record sheet. A record sheet was made based on scientific evidence.⁵⁰ A record was used for the falls, hospital stays, and changes in daily living aids (walker/cane/wheelchair/glasses/hearing aid) that participants experienced throughout the project.

Statistical analyses

Statistical analysis was conducted in R-project for Statistical Computing (version 4.1.2; GNU project: Auckland) and IBM SPSS Statistics (version 27.0; IBM; Chicago). Descriptive analysis was done using means and standard deviations (\pm SD) and frequencies or percentages. On the

other hand, methodologies and models were proposed because the data set obtained consisted of repeated measures.

Mixed models were carried out in the analysis to determine the association of TST with activity.⁵¹ Taking 'participant' and 'days' as the fixed effects of the model so that the model considers the inherent variability that arises from the differences between participants, and also the different factors that may be due to the season of the year and cannot be easily controlled. For this model, a transformation of the response variable 'steps' was carried out to scale it: $Y = TST + (days/participant)$.

The Granger test was used to check whether any of the variables obtained could predict a time series.⁵¹ Specifically, it was used to find out whether, temporally, the evolution of sleep quality and quantity are good predictors of the progress of the activity. In this case, a $p < 0.05$ indicates that a variable is a good predictor.

The time series were used to know if there was a relationship between days with fewer steps and falls. The time series was divided into three components (trend, seasonality, and residual). It was highlighted that the seasonality was 7 days because the data collection is daily, and the duration of the series is one year. In addition, it was considered that there would be a trend since participants hadn't had the same activity every day of the week.

Spearman's rank correlation coefficients were used for determining the association between sleep and its parameters and the different assessment tools.⁵¹ This methodology was used because the data from scales were ordinal. Moreover, only post-data were taken into because it was measured after recording sleep and activity data. Sleep parameters were coded to know the influence of sleep quality for the analysis:

- Sleep period (light sleep/deep sleep). A value >1 indicates more light sleep hours than deep sleep, <1 indicates less hours of light sleep than deep sleep, and 1 implies the same hours in each stage.
- Total Awake (WASO/(Deep + Light)). The ratio of time awakes to time asleep. A value >1 implies more hours awake than sleeping, and <1 indicates more hours of asleep time than awake time.

The Wilcoxon test for paired data was used to compare the values of the pre-scales and post-scales.⁵¹ In addition, time-series were used to study the temporal evolution of the different variables. These time series were univariate and were obtained by averaging the values of the 21 study participants for each day. Although each time series is divided into three components, we focussed on extracting the trend since we wanted to know whether the variables improved or worsened over time. To find this trend, we fit a local polynomial regression model: $Y = f(x)$. (f indicates the trend).

Finally, we tested the relationship between sleep and activity variables and environmental factor parameters using Spearman correlations.⁵¹

Table 2. Descriptive variables.

Measure	N (%) / Mean \pm SD
Xiaomi Mi Band 2	
Sleep	
TST	321.90 \pm 97.61
TST \leq 7–8 h. (420–480 min)	19 (90.47%)
Light sleep	221.21 \pm 81.49
Deep sleep	100.65 \pm 33.60
WASO	39.87 \pm 29.13
Activity	
Steps	1623.29 \pm 2080.02
Steps \leq 3000 daily steps	16 (76.21%)
Assessment tools	
Lobo MCE \leq 23	12 (57.14%)
VAS EQ 5D-5L \leq 50	8 (38.09%)
Barthel \leq 60	11 (52.38%)
Tinetti \leq 24	17 (80.95%)
PSQI \leq 5	20 (95.23%)
Falls	
Average of falls	1 \pm 2
Falls \leq 1	7 (33.3%)
Mobility aids	
Walker	12 (57.1%)

TST: total sleep time; WASO: wake after sleep onset; MCE: mini-cognitive examination; PSQI: Pittsburgh Sleep Quality Index.

Results

Statistical description about Xiaomi Mi Band 2 and assessment tools

All participants used the Xiaomi Mi Band 2 for one year, obtaining 61,320 recorded sleep and activity data. The data from this device (Table 2) refer that most of the participants slept an average of 321.90 \pm 97.61 min, which means less than 7 h per day. Specifically, the hours of light sleep were greater than deep sleep. Moreover,

participants walked a mean of 1623.29 \pm 2080.02 steps, which means less than 3000 steps per day in most cases.

Data from assessment tools showed that participants at the end of the study had a higher cognitive impairment (57.14%), worst perception of their quality of life (38.09%), greater dependence on ADLs (52.38%), an increased risk of falling (80.95%), and the same subjective perception of sleep quality (95.23%). As for the data associated with fall history, 7 people (33.3%) suffered any fall during the study.

Regarding assistive products, it is highlighted that 76.2% of older residents used glasses. The use of mobility aids was changed throughout the study. At the beginning of the study, 33.33% of participants didn't use mobility aids, and 28.6% used mobility aid like a walker or cane, respectively. However, at the end of the study, several participants began to use a mobility aid or changed the type of aid. The walker was the most used mobility aid (57.1%).

Sleep and activity

We investigated whether there was a relationship between the duration of sleep and the activity (steps) that older people performed during a year. The relationship between both parameters was significant and positive, but the correlation was weak ($r = 0.2643$; $p < 0.001$).

The mixed model (see in Table 3) shows that the effect of variable 'days' on activity was not significant, but the influence of TST on activity was significant. This result meant that for each extra hour of TST, the activity of the older person could increase 3.06 times.

In addition, the predictions made with the mixed model were accurate, especially for the low number of steps. The adjusted R^2 of the model was 0.8, with the relative share of fixed effects being 0.007, meaning that most of the variability of the data set could be due to random effects on the 'person' variable.

Likewise, we tested whether the quantity and quality of sleep influenced activity using the Granger test (Table 4). Results referred that only the quantity of sleep could be a predictor of activity. The quality of sleep, measured with the variable 'Light/Deep Sleep' and 'WASO/TST', were not predictors of activity, having a $p > 0.05$.

During the project, we could observe a total of 25 falls through the analysis of steps. These falls were identified in March, September, October, and November. The results reflect a possible association between the days, when people fell, and the low activity of the participants during the following days. Likewise, the dates with more steps than 'expected' (>2.5 SD in the residuals) were March, April, June, and September. Whereas the dates with fewer steps than 'expected' (<-2.5 SD in the residuals) were February, August, and September. No statistical relationship was found between sleep and falls.

Table 3. Mixed model on sleep and activity associations.

Variable	Value (Y)	St Error	Df	t-value	p-value
(Intercept)	17.95	4.11	7657	4.36	<0.001
Days	0.00067	0.0022	7657	0.29	0.765
Total sleep time	3.06	0.096	7657	31.61	<0.001

Table 4. Association between sleep and activity variables using the Granger test.

Variables	F-statistics	p-value
Activity-TST	139.21	<0.001
Activity-Light/deep sleep	0.0202	0.88
Activity-WASO/TST	2.36	0.12

TST: total sleep time; WASO: wake after sleep onset.

Sleep parameters and assessment tools

Table 5 shows the associations between sleep parameters and assessment tools using Spearman correlations. The results referred to strong and positive associations between TST and light sleep variables with the perception of quality of life, cognitive status, level of independence in ADLs, and risk of falling. However, the perception of sleep quality was moderately negative related to the TST variable and strongly negative related to the light sleep variable.

Furthermore, we observed negative and high correlations between WASO and the scores of the assessment tools, except with the PSQI scale, which presented a positive association with the WASO variable. Concerning the deep Sleep variable, only weak and positive associations were reported with the tools associated with cognitive status, level of dependence on ADLs, and the risk of falling.

Table 6 reports the relationship between sleep quality and different assessment tools. The results showed no statistically significant correlations between the sleep period (light/ deep sleep) and the EQ 5D-5L, MCE, and Barthel index. Although, sleep period was associated weakly and positively with the Tinetti scale and weakly and negatively with the PSQI scale. However, the proportion between WASO and time sleep showed a negative and high association with the assessment tools EQ 5D-5L, Lobo MCE, Barthel Index, and Tinetti. But a positive and high relation with the PSQI scale.

Environmental factors and their relationship with sleep and activity

The results showed a statistically significant relationship between TST, and the different environmental factors analysed.

We observed weak and positive correlations were found between TST and temperature ($\rho=0.3571$; $p<0.001$) and hours of sun ($\rho=0.3023$, $p<0.001$). However, low, and negative correlations were identified between TST and humidity ($\rho=-0.0822$, $p<0.001$) and rain ($\rho=-0.268$, $p<0.001$).

Moreover, as shown in Table 7, positive and strong Spearman correlations were also obtained between TST and light sleep stages and temperature. Likewise, we identified positive but weak associations between deep sleep and WASO with temperature and hours of sun. Nevertheless, we found a negative and low relation between rain and humidity and all sleep variables.

Concerning activity, the results reflected that the average of daily steps of the participants were weakly associated with the different environmental factors. Thus, the data showed a positive and weak association between temperature ($\rho=0.228$, $p<0.001$) and hours of sun ($\rho=0.1645$, $p<0.001$) with the activity of the participants. In contrast, humidity ($\rho=-0.196$, $p<0.001$) and rain ($\rho=-0.201$, $p<0.001$) had a negative and low correlation with participants' daily steps.

Influence of the passage of time on the daily life of nursing home residents

Table 8 shows the relationship between pre-data and post-data of the assessment tools. Thus, the correlations between the passage of time and all assessment tools were strong and negative, except for PSQI, which presented a positive association.

Moreover, we investigated whether the passage of time influenced the quality and quantity of sleep. Figure 1 in plot 'a' showed that the TST of the participants tended to increase in summer season while at the beginning and at the end of the year TST decreases, with a prominent tendency at the end of the year. Also, there was a clear downward trend in the TST quantity, both deep and light sleep. Besides, the time awake remained stable for the study (see plot 'b' in Figure 1).

In terms of sleep quality, Figure 2 in plot 'a' shows an upward trend between the proportion of awake total to TST which was associated with a potential worsened sleep quality over time. Likewise, as shown in Figure 2 in

Table 5. Spearman correlations between the quantity of sleep parameters and assessment tools.

Variables	Variables			
	TST	Light sleep	Deep sleep	WASO
EQ 5D-5L	0.637***	0.709***	0.177	-0.684***
Lobo MCE	0.753***	0.724***	0.591***	-0.720***
Barthel index	0.866***	0.874***	0.507*	-0.806***
Tinetti	0.926***	0.935***	0.472*	-0.822***
PSQI	-0.508***	-0.860***	-0.415	0.817***

TST: total sleep time; MCE: mini-cognitive examination; PSQI: Pittsburgh Sleep Quality Index; WASO: wake after sleep onset.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 6. Spearman correlations between the quality of sleep parameters and assessment tools.

Variables	Variables	
	Sleep period (Light/deep sleep)	WASO/(Light + Deep sleep)
EQ 5D-5L	0.274	-0.759***
Lobo MCE	0.431	-0.759***
Barthel index	0.409	-0.886***
Tinetti	0.481*	-0.907***
PSQI	-0.491*	0.877***

MCE: mini-cognitive examination; PSQI: Pittsburgh Sleep Quality Index.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

plot 'b', the trend was not clear, but we observed a slight decline in sleep quality in the last portions of the graphic. As shown in Figure 3, the results report that the daily steps increased during the months of summer. Nevertheless, the trend descended much more in the last months of the study compared to the first months.

Discussion

This longitudinal study analysed the influence of sleep and its changes concerning the functionality and health status of older people who lived in a nursing home, followed-up with the Xiaomi Mi Band 2 for one year. This study, as opposed to other studies that analysed sleep in an older population living in a nursing home, combined the use of assessment tools (MCE, EQ5D-5L, Barthel Index, Tinetti, and PSQI

and the Xiaomi Mi Band 2 to understand the implications of sleep on the daily lives of nursing home residents.

One of the first objectives of this study was to analyse the relationship between participants' sleep and activity data obtained by the Xiaomi Mi Band 2. The first results focussed on participants' sleep duration and the number of steps. These data were similar to those reported in previous studies,^{52,53} suggesting that both the TST (5.36 ± 1.62 h), with more light than deep sleep and with WASO of more than 30 min and activity (1623.29 ± 2080.02 steps) were inadequate and below the recommended values for the older population.^{46,47}

Our analysis shows a significant but weak association between sleep duration and activity ($r = 0.2643$, $p < 0.001$). Thus, it suggests, as in the work of Kuok et al.⁵³ and Kim et al.,⁵⁴ that those older residents who had higher sleep duration, could be more active during the day.

The present study calculated through a mixed model how the variable 'days', associated with the days of the year and related daily factors, could influence the sleep and activity of the older participants.^{54,55} The result indicated that this variable didn't affect the sleep and activity of older participants. But if, it indicated that the TST could increase 3.06 times the daily steps performed by the participants, as the Granger test values indicated.^{54,55}

Regarding falls, seven participants had any falls, a total of 25 falls during the study, so the falls were usual in these participants.^{12,14} Scientific evidence reports that the risk of falling influences negatively the quality and duration of sleep and activity in the older population.^{12,14} However, our results didn't show significant associations between falls and sleep. But if, they suggest that falls could be a factor of inactivity in the older person, and a low activity could be a possible predictor of falls (>2.5 SD in the residuals). Against these results, we recognize that it is difficult to determine these findings due to the small sample size.

This study also analysed the association between assessment tools and sleep quality and quantity. Some studies

Table 7. Spearman correlation between environmental factors and sleep parameters of participants.

Variables	Variables			
	TST	Light sleep	Deep sleep	WASO
Temperature	0.601***	0.650***	0.302***	0.274***
Humidity	-0.489***	-0.472***	-0.352***	-0.150***
Rain (l/m ²)	-0.350**	-0.327***	-0.296***	-0.134*
Hours of sun	0.507***	0.489***	0.350***	0.154**

TST: total sleep time; WASO: wake after sleep onset.

*** $p < 0.0001$; ** $p < 0.01$; * $p < 0.05$.

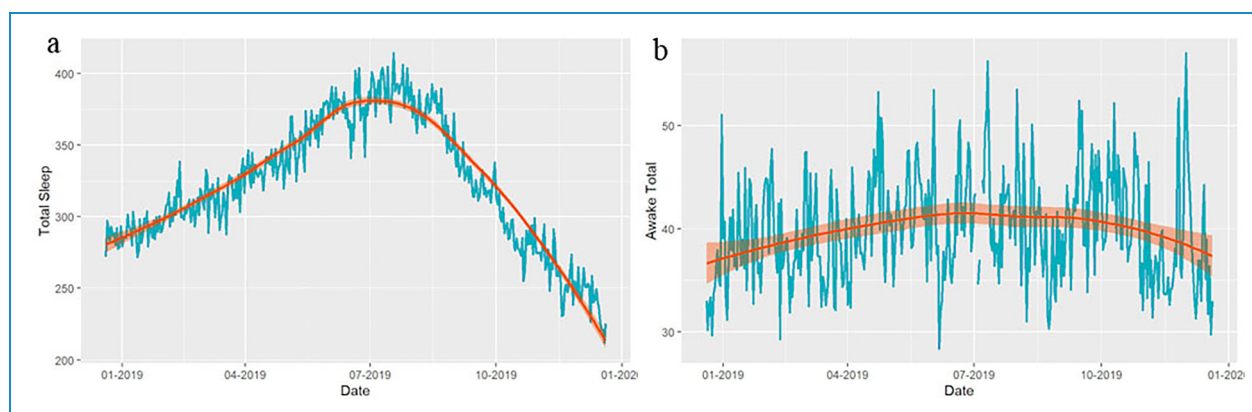
Table 8. Associations between the passage of time and assessment tools.

Variable	Pre ^a (Mean \pm SD)	Post ^b (Mean \pm SD)	IC 95%	V	p-value	r
EQ 5D-5L	68.42 \pm 14.84	56.66 \pm 15.35	0.66–0.91	5.31	<0.001	0.79
MCE	25.33 \pm 3.56	22.66 \pm 4.55	0.78–0.90	5.25	<0.001	0.84
Barthel index	72.85 \pm 26.24	62.38 \pm 27.36	0.64–0.85	4.79	<0.001	0.75
Tinetti	17.80 \pm 8.62	15.66 \pm 8.76	0.63–0.84	4.65	<0.001	0.73
PSQI	9.14 \pm 2.74	12.04 \pm 4.52	-0.90–0.74	-inf.	<0.001	-0.82

MCE: mini-cognitive examination; PSQI: Pittsburgh Sleep Quality Index.

^aPre scales

^bPost scales.

**Figure 1.** Graphical representations of the total sleep time (TST) (a) and the awake time (b) of the participants during the study.

refer that sleep problems can be a risk factor to develop cognitive impairment, dependence on ADLs, and risk of falling. In the same way, older people, who have these alterations in their functioning and health status, usually

have sleep problems like insomnia, parasomnia, or sleep apnea^{2,12,13,56–58}. Specifically, our outcomes also reflected a significant relation between sleep parameters with these variables. Moreover, as Martins da Silva et al.,¹⁴ our

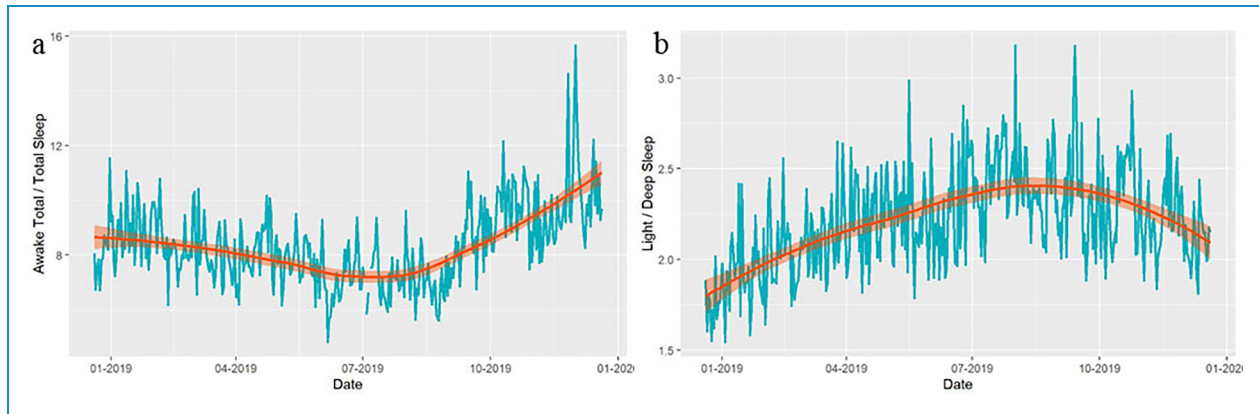


Figure 2. Graphical representations of the sleep quality (awake total/total sleep) (a); (light/deep sleep) (b) of the participants during the study.

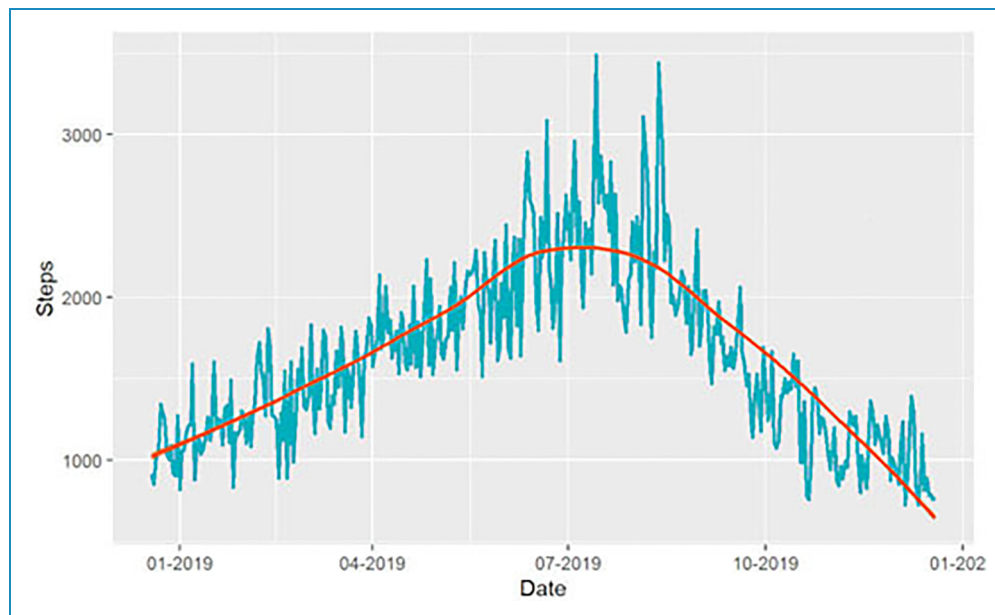


Figure 3. Graphical representation of the daily steps of the participants during the study.

analysis showed that the sleep quality and quantity positively contributed to daily activity and the performance of ADLs of participants.

The evidence indicates that people, who have a positive score in their sleep quality calculated through specific assessment tools such as PSQI, have an adequate quantity of sleep according to the National Sleep Foundation.^{15,46} However, our findings suggested that the participants, who had an appropriate period of sleep according to the National Sleep Foundation, referred a lower quantity ($\rho = -0.508$, $p < 0.001$) and poor quality ($\rho = 0.877$, $p < 0.001$) of sleep by PSQI. Deepening the results, we observed that deep sleep hadn't got a significant association

with PSQI, therefore, this controversy could be related to the TST and, specifically, with light sleep. In other words, more light sleep could be associated with poor quality of sleep.

Authors like Wang et al.⁵² explain that different factors, which can cause alterations in the daily functioning and health status of the person, also can lead to a reduction in their quality of life.⁵⁹ In this case, sleep could influence the quality of life since the correlation between EQ5D-5L and WASO was negative ($\rho = -0.684$, $p < 0.001$), in contrast with TST ($\rho = 0.637$, $p < 0.001$) and light sleep ($\rho = 0.709$, $p < 0.001$) that were positives. Moreover, our findings suggested that quality of life also could be indirectly

related to cognitive status, dependence on ADLs and risk of falling, taking into account that these variables influenced the quality and quantity of sleep.⁵⁹

We analysed whether different environmental factors influenced the sleep and activity performed by the older adults. The results highlight those environmental factors like temperature, rain, hours of sun and humidity, had a moderate or weak effect on quantity and quality sleep, and activity.

Thus, higher temperature and hours of sun could be positive factors with a weak association in relation to sleep and activity. By contrast, humidity and rain could have a low and negative impact on sleep and activity. In this way, some studies mention the influence of environmental factors on sleep, but they don't deep on the analysis of specific factors.^{48,49}

Lastly, we researched the changes on the health and daily functioning status of the participants throughout the study. The evidence refers to some factors as a passage of time can change and affect the sleep architecture.^{4,5,60} Epidemiological studies refer that sleep problems increase with age and stabilize around 75 years old.^{8,61} Moreover, the National Sleep Foundation identified the following factors naps, WASO, or changes in sleep routines and habits.⁴⁶ In this case, we found that the quality and quantity of sleep suffered changes along with the study, emphasizing that sleep seems to improve in summer and get worse at the end of the study. In the same way, like sleep, the scores of assessment tools and activities got worse at the end of the study.

Limitations

The first limitation of this study is the sample size. Even though there were 44 residents in the nursing home, only 21 met the inclusion criteria. The main exclusion criterion was that part of the study population presented moderate or severe cognitive impairment levels. Moreover, some residents didn't agree to wear the Xiaomi Mi Band 2 device due to discomfort in wearing and sleeping with it. For these reasons, the results of the study cannot be decisive. Therefore, it is considered that further studies should look for other alternatives (i.e., changing the material of the band) to ensure the device's comfort and expand it to other nursing homes.

Another limitation detected was the inclusion of older adults who took medications that could affect their sleep. At the beginning of the study, the authors didn't contemplate this variable. However, it must be included in the exclusion criteria of further research to avoid potential biases.

Furthermore, the research group was conscious that there was data loss because the routines and situations derived of daily living of older adults from a nursing home. In addition, the Xiaomi Mi Band 2 wristband is not a device

scientifically validated. Accordingly, although there are already study protocols⁴⁹ working on it, the data of this device should be taken with care.

Clinical implications

The use of Xiaomi Mi Band 2 combined with the assessment tools conforms to an assessment dossier complementary that helps to contrast the subjective data with the objective data. In addition, participants became more aware of their sleep and daily activity through the use of this device. All of this can facilitate the clinical practice of health care professionals.

Conclusions

The main conclusion of this study is that sleep and the parameters analysed by the Xiaomi Mi Band 2 can influence the quality of life and occupational performance of older people living in nursing home. The study participants had a TST below the recommended values. In addition, these values could negatively influence the daily activity, which was performed in the nursing home. Sleep and the parameters light and deep sleep had a positive relationship with quality of life, independence in ADLs, cognitive status, risk of falling, and a negative relation with awake time. However, the data from the perception of sleep negatively had an association.

Hours of sun and the high temperature had a positive and weak impact on the quantity and quality of sleep. But rain and humidity had a negative and weak impact. The changes on health and daily functioning status got worse in all the parameters and assessment tools during the study. Lastly, Xiaomi Mi Band 2 could be an objective tool to assess the sleep of older adults.

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Appendix 1

See Table 9.

Table 9. Assessment tools.

Assessment tool	Description	Score
Lobo mini-cognitive examination	The participants' cognitive status was evaluated using the Lobo MCE, a brief test used to detect the existence of cognitive impairment ⁴⁰ .	A total score between 0 and 23 indicates the presence of cognitive impairment, while a total score between 23 and 35 suggests mild cognitive impairment or absence ⁴⁰ . Also, the Reisberg GDS classified the cognitive function of the participants in the following stages based on the score obtained on the Lobo MCE: 'No cognitive decline' (30–35 points), 'Very mild cognitive decline' (25–30 points); 'Mild cognitive impairment' (20–24 points), 'Mild dementia' (15–19 points), and 'Moderate dementia' (0–14 points) ⁴¹ . It is highlighted that of Lobo MCE was used as a screening tool to detect the presence of cognitive impairment and to determine the association between the cognitive status and the rest of the variables. So, the GDS was only used to ascertain the baseline cognitive status of the study population at the beginning of the study.
EuroQol 5D-5L	The participants' perception of the quality of life and health status was analysed using the EQ 5D-5L scale ³⁷ . It has made up of two components. The descriptive system includes five dimensions (mobility, personal care, daily activities, pain/discomfort, and anxiety/depression) ³⁷ .	Its score is based on five points assigned to each of the dimensions according to the severity level (1 = Absence of problems, 5 = Presence of severe problems) that provide a profile (i.e.,12332) on health status ³⁷ . The VAS extends from 0 (the worst imaginable state of health) to 100 (the best imaginable state of health) ³⁷ .
Barthel Activities of Daily Living Index	This hetero-administrated tool allows measuring the performance in ADLs ⁴² .	It values the level of independence in some daily activities and has a range of total scores between 0–100, with 0 the maximum dependence and 100 the maximum independence. The total scores are interpreted as follows: <20 (total dependence), 21–60 (severe dependence), 61–90 (moderate dependence), 91–99 (mild dependence), 100 (independence/90 if the person is wheelchair) ⁴² .
Tinetti scale	This tool assesses the person's gait and balance. It is used to detect the risk of falling.	A higher score indicates a higher functionality, and a lower score reflects the possibility of fall risk ⁴³ . The balance scale has a maximum score of 16 points, and the gait scale has a score of 12 points. The total score range is 0–28, with 0 as the maximum level of risk of falling and 28 as the minimum level of risk of falling ⁴³ . The different scores can be interpreted as follows:

(continued)

Table 9. Continued.

Assessment tool	Description	Score
Pittsburgh Sleep Quality Index	The PSQI assesses sleep quality. Specifically, it has 19 items associated with quantity, quality, duration, latency, and sleep efficiency ³⁸ .	<p><19 points mean a high risk of falling, 19–24 represents a moderate risk of falling, and <24 reflects low fall risk⁴³.</p> <p>The total score of the PSQI scale is the result of adding seven components, rated from 0 to 3. The resulting score ranges from 0 to 21, a total score of 0 indicates no sleep difficulties, and a score of 21 means severe difficulties in all sleep areas, so the higher score, the worse sleep quality³⁸. However, previous studies referred to more appropriate cut-off scores to indicate 'poor sleep quality' in groups as susceptible to sleep problems as the older population^{6,39}. Thus, following the indications of these authors, it was considered: that a PSQI total score of <5 indicated 'good sleep quality'; 5–9 points indicated 'modest sleep quality'; and >10 points indicated 'poor sleep quality'^{6,39}.</p>

MCE: mini-cognitive examination; PSQI: Pittsburgh Sleep Quality Index; VAS: Visual Analogue Scale; GDS: Global Deterioration Scale; ADL: activities of daily living.