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Interactions between sleep-wake cycle on balance control of elderly people

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***Abstract*—Analysis of sleep-wake cycle in elderly people plays an important role in the quality of life of this population. The goal of this study is to analyze circadian rhythm of elderly people with actigraphy, subjective questionnaires and their relationship with balance control evaluated by center of pressure (COP) variables. The sleep-wake cycle of nine elderly subjects were evaluated using a wearable actigraph for 14 days. Questionnaires which evaluates chronotype, sleep quality and daytime sleepiness were administered and their balance control during quiet standing position was assessed by portable force platform. Measures of active phase amplitude (M10), rest amplitude (L5) total sleep time (TST) and time in bed (TIB) from actigraphy data and questionnaires results were correlated with COP variables. The actigraphy parameter that shows larger nocturnal activities (L5) showed positive correlations with larger COP excursions, whereas variability of M10, which can be interpreted as smaller routines of daily activities, showed negative correlations. Besides, TST and TIB showed positive correlations with COP variables.**

***Index Terms*—Actigraphy, actimetry, postural control, center of pressure, elderly, circadian rhythm**

I. Introduction

Aging is a natural process that causes physiological and cognitive changes in the individual [1] [2]. It is predicted that by 2050, elderly people will represent 16% of the world population [3]. During the process of aging, there are changes in sleep-wake cycles and in sleep continuity and fragmentation which can affect their overall quality of sleep, in which case the sleep quality research in elderly populations can benefit their quality of life and prevent illnesses and falls [1].

In this way, actigraphy is a non-invasive method that allows assessing the quality of an individual's sleep from the study of activity patterns of the human circadian rhythm during the sleep-wake cycle. This method measures sleep and circadian parameters that, together with other qualitative methods of sleep information, can be used to assess different factors which cause sleep disorders [4].

Besides, it is known that acute and chronic sleep deprivation causes balance control disorders that can be identified by postural detection methods [5] [6]. Furthermore, analysis of human postural control by force platform is a commonly used method in the biomechanics and motor control literature [5].

Different equipment can be used to study the stability of subjects during bipedal quiet stance. In this work, force platform is employed as a tool for experimental purposes to measure postural oscillations, which are movements in both the front-to-back (anteroposterior) and side-to-side (medio-lateral) directions. The force platform provides information about the Center of Pressure (COP), a point in 2D space representing the average distribution of ground reaction forces on the foot surface [7]. Higher COP oscillation values are commonly associated with lower balance control [8]. Thus, the COP displacement is used to assess the control of balance of an individual.

A recent systematic review showed that poor sleep quality negatively affects postural control [5]. More specifically, a study in young people showed that chronic sleep deprivation affects balance control [6]. We hypothesized that a similar effect occurs in the elderly, however the elderly sleep patterns are different from the young [9]. Moreover, the deterioration of balance control is more critical for the elderly due to the risk of a fall and its devastating consequences, like hospitalization, loss of independence, and consequently death [10].

To address this problem, the goal of this study is presented in the use of non-parametric circadian rhythm analysis attributed to actigraphy to identify which sleep elements influence the deterioration of balance control in elderly population. We hypothesize that actigraphy results that represent worse sleep quality are correlated with a decline in balance control performance, measured by the force platform.

For this purpose, we performed an experimental study with actigraphy, questionnaires and a portable force platform to identify specific balance control parameters affected by poor sleep quality in the elderly population. Actigraphy was employed to quantitatively measure sleep parameters of the circadian rhythm and subjective questionnaires were used to gather additional information.

II. Actigraphy Design

The model of the wrist actimeter used in the experiments was an ActTrust 2 (Condor Instruments Ltda). This equipment has a 3-axis accelerometer, two temperature sensors (one in contact with the wrist and the other external) and a RGB light sensor. Besides, the device uses a Proportional Integrative Mode (PIM) to capture the user movement and processes with epoch of 60 seconds.

The activity patterns can be processed into two types of activity logs: amplitude of the active phase (M10) and amplitude of rest (L5). The former one represents the 10 hours per day of maximum movement consecutive and the latter is the 5 hours per day of minimal movement consecutive.

To help define the sleep period of the subjects, they received a sleep diary app developed by Condor Instruments to record when they lay in bed and get up. Thereby, the algorithm processes two types of data: Total Time in Bed (TIB) and Total Sleep Time (TST).

The data was downloaded and processed using the software ActStudio (Condor Instruments Ltda., SP, Brazil). Fig. 1 and 2 show the raw data from the actimeter and actogram, respectively.

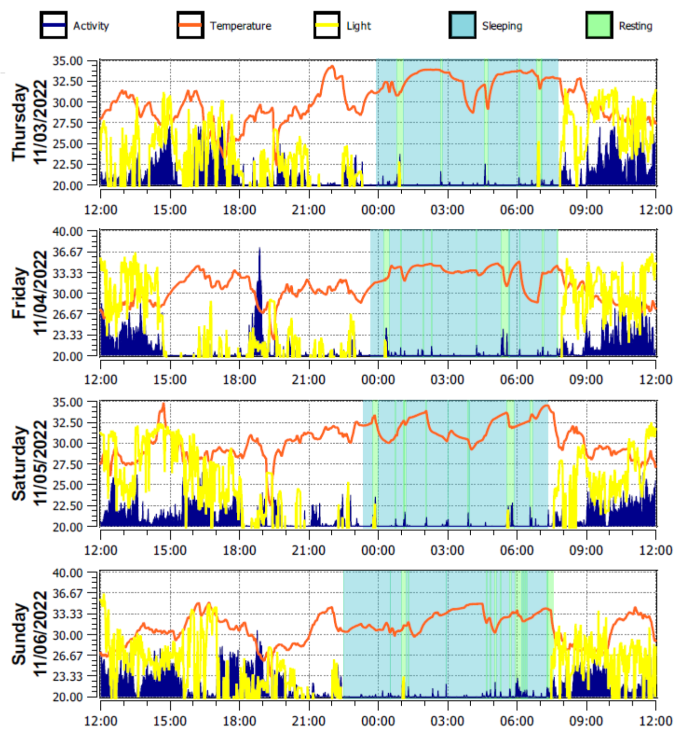

Fig. 1. Example of raw actigraphy data from a 4-day of continuous actimeter use.

III. Experiment

A. Subjects

Nine elderly subjects (mean age = 68.2 ± 4.79 years; weight: 71.2 ± 16.5 Kg; eight women) were evaluated with actigraphy after two weeks of continuous use of the watch. The exclusion criteria were consumption of drugs that may affect sleep and diagnoses of psychiatric or sleep disorders.

The study was approved by the Ethics Committee of the University Hospital of the University of São Paulo.

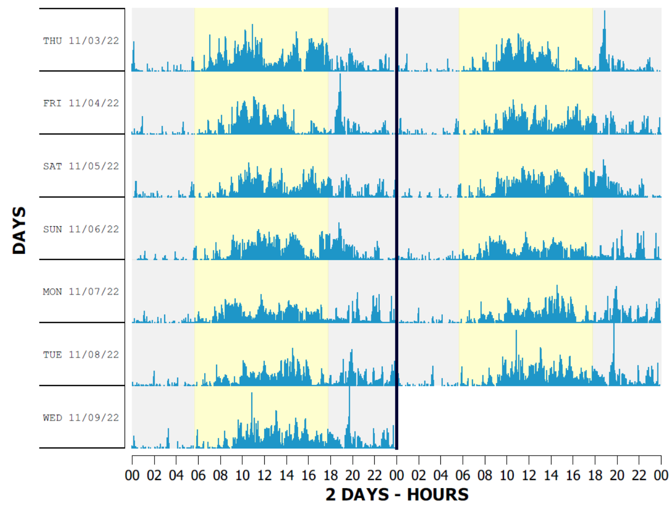

Fig. 2. Example of actogram with the sleep intervals.

B. Experimental Procedures

The instructions were to maintain the watch at the wrist and only take it off when taking a shower. After two weeks, the subjects postural control was evaluated using a low-cost and portable force platform (Wii Balance Board, Nintendo of America Inc) in a quiet upright posture in two conditions: with and without visual information. Previous work has shown that it is possible to assess sleep deprivation using this equipment [11].

In the first condition, the subject was asked to look at a visual target, approximately two meters away and two meters height, then remain standing for 60 seconds, trying to produce the minimal postural oscillations as possible. After the first test, the participants were instructed to close their eyes and maintain the same posture for another 60 seconds. In all tests, participants were barefoot.

C. Questionnaires

Thereafter, three questionnaires were applied: Morningness-Eveningness Questionnaire (MEQ), Pittsburgh Sleep Quality Index Questionnaire (PSQI) and Epworth Sleep Scale (ESS). MEQ is self-assessment questionnaire that uses scores of 19 items to identify daytime preferences (morningness or eveningness) of the subject [12]. PSQI evaluates disturbances and quality of sleep with seven components divided into nineteen items [13]. Finally, ESS measure the subject overall level of daytime sleepiness with eight questions that rate the individual's chance to falling asleep on a 4-point scale [14].

On average, most subjects are part of the moderate morning chronotype group (MEQ=58,8), have significant sleep disturbance (PSQI=6,09) and have an average amount of daytime sleepiness (ESS=7,9). The questionnaires did not show any correlation with COP parameters.

D. Software and COP Parameters

The BrainBlox software was used to obtain the values of the four force sensors at the corners of the board and assess them to estimate the position of x and y components of COP. This software was developed by the Department of Integrative Physiology at University of Colorado Boulder [15].

The COP signal was filtered by a second order Butterworth low pass filter and evaluated by a routine performed in Matlab to identify parameters validated in the force platform posturography literature [8]. Thus, the COP variables and their corresponding abbreviations and descriptions are presented in Table I. Moreover, a typical COP displacement plot of the COP time-varying coordinates, also known as a stabilogram, can be view at Fig. 3.

TABLE I
LIST OF COP PARAMETERS, AP: ANTEROPOSTERIOR AND ML: MEDIOLATERAL.

Variable	Description
MS	Mean Sway of COP.
MSAP and MSML	Mean sway of the COP in the AP and ML directions.
MSAPstd and MSAPstd	Standard deviation of COP mean sway in the AP and ML directions.
AREA	COP coverage area.
MaxAP and MaxML	Maximum distance covered by the COP in the AP and ML directions.
VEL	Mean velocity of COP.
VELAP and VELML	Mean velocity of COP in the AP and ML directions.
TSD	Total COP displacement.

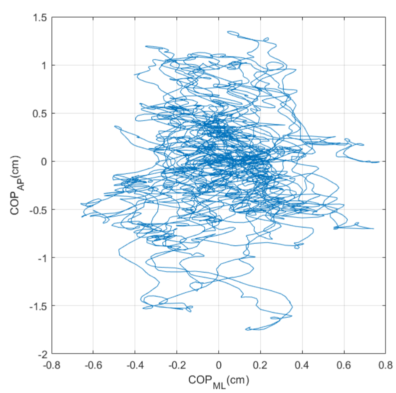

Fig. 3. Typical 60-s stabilogram for an elderly individual during quiet standing. Mediolateral and anteroposterior COP displacements are plotted along the x-axis and y-axis, respectively

E. Data Analysis

COP, questionnaires index and actigraphy variables were correlated using Pearson correlation coefficient to measure the strength and direction of the relationship between the variables. The statistical analysis was performed using Jamovi software (Version 2.3).

IV. RESULTS

The actimetry variables showing significant correlation with the posturography variables ($p \leq 0.05$) were: maximum of L5 (L5max), standard deviation of L5 (L5std), M10 standard deviation (M10std), average time in bed (TIB) and average total sleeping time (TST). In all cases, the test assumption was confirmed.

A. Correlation Between L5 and COP Variables

All statistically significant correlations between L5 and COP variables were positive and were only present in the condition with eyes open, as show in Table II.

TABLE II
L5 AND COP PARAMETERS CORRELATIONS WITH P-VALUE AND PEARSON'S R. ALL CORRELATIONS ARE POSITIVE AND WITH EYES OPEN CONDITION.

Sleep Variable	**COP Variable (Eyes Open)**	**p-value**	**Pearson's r**
L5max	MSAP	0,028	0,721
	MSAPstd	0,026	0,729
	MaxAP	0,011	0,791
L5std	MSAP	0,035	0,701
	MSAPstd	0,032	0,709
	MaxAP	0,018	0,759

B. Correlations Between M10, TST, TIB and COP Variables

As presented in Table III, the statistical results revealed that the standard deviation of the M10 has a negative correlation with the same COP variables in which the L5 has a correlation. Besides, there is a positive correlation between TST and TIB with COP variables. In all cases, there is only correlation in tests with eyes closed condition.

TABLE III
M10, TST, TIB AND COP PARAMETERS CORRELATIONS WITH P-VALUE AND PEARSON'S R. ALL CORRELATIONS ARE WITH EYES CLOSED CONDITION.

Sleep Variable	**COP Variable (Eyes Closed)**	**p-value**	**Pearson's r**
M10std	MSAP	0,021	-0,748
	MSAPstd	0,035	-0,701
	MaxAP	0,031	-0,715
TST	MSAP	0,031	0,713
	MSAPstd	0,027	0,725
	TSD	0,007	0,818
	MaxAP	0,026	0,73
	VEL	0,007	0,818
	VELAP	0,003	0,858
TIB	TSD	0,031	0,714
	VEL	0,031	0,714
	VELAP	0,013	0,782

C. Differences of Anteroposterior COP Variables Related to Visual Feedback

Visual feedback plays a significant role in influencing postural sway, mostly in anteroposterior (AP) direction when in quiet standing [16]. Thus, the results in Table IV show that the speed and COP parameters in the AP direction are, on average, lower with the eyes open condition.

TABLE IV
COP PARAMETERS MEAN AND STANDARD DEVIATION WITH BOTH VISUAL FEEDBACK CONDITIONS.

Eyes Open				
	MSAP	**MAXAP**	**VEL**	**VELAP**
Mean	0,305 cm	1,4 cm	1,87 cm/s	1,15 cm/s
Standard Deviation	0,093 cm	0,455 cm	0,498 cm/s	0,205 cm/s
Eyes Closed				
	MSAP	**MAXAP**	**VEL**	**VELAP**
Mean	0,39 cm	1,86 cm	2,36 cm/s	1,67 cm/s
Standard Deviation	0,103 cm	0,6 cm	0,835 cm/s	0,837 cm/s

V. DISCUSSION

A higher L5 corresponds to a larger nocturnal movement of the individual, which can be related to a lower sleep quality, showing sleep fragmentation through wake after sleep onset and lower performance in the balance control test [4] [6]. The results showed a positive correlation between L5max, L5std and posturography variables such as MSAP, MSAPstd and MaxAP suggesting that the worse sleep quality detected by actigraphy may be responsible for an increase in balance control parameters with eyes open condition in the AP direction.

In this case, higher COP parameters are associated with a less stable posture. As presented in previous studies of standing balance control, there is a prevalence of high values in COP parameters in AP direction which characterize worse performance of postural control, especially in elderly populations [9] [16].

It is then inferred that the positive correlations between COP variables and the amplitude and variability of L5 can be related to the deterioration of motor balance control caused by greater nocturnal activities (worse sleep quality). However, lower sleep quality was not related in substantial higher values for COP-related variables in the absence of visual feedback.

Besides, M10 is a measure of the activity, in general, a higher activity is related to a better physical condition. Since only the variability was statistically correlated to COP variables, it is possible to infer that the subjects do not have a well-defined routine, which possibly results in worse sleep and, therefore, lower balance control.

However, this condition may only be detected under more challenging situations, such as the eyes closed condition and with unstable surfaces. In a previous work that analyzed acute sleep deprivation and posture steadiness, the most sensitive COP variables are those in AP direction and was more prominent in the tests with eyes closed [11]. In this sense, this work is in agreement since it is noteworthy that there is a higher mean and standard deviation in the variables with eyes closed in the AP direction and also in the velocity variables, as show in Table IV.

In elderly populations, the relationship between longer sleep time and sleep quality deteriorates as there are greater nighttime awakenings [17]. Therefore, the positive correlation between the TST and TIB variables with the COP parameters occurs because the elderly subjects who spend more time resting may have less actual restful sleep. To adress this problem, future works could use polysomnography with actigraphy to study this subject.

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