Daily Social and Physical Activity Increases Slow-Wave Sleep and Daytime Neuropsychological Performance in the Elderly

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Abstract: Decreased levels of physical and social activity associated with aging can be particularly pronounced in residents of assisted living facilities. Reduced exposure to important behavioral and time-giving cues may contribute to the age-related changes in circadian rhythmicity and sleep. The present study was conducted to test the hypothesis that an enforced schedule of structured social and physical activity (0:900 to 10:30 and 19:00 to 20:30 daily for two weeks) can have beneficial effects on circadian rhythmicity, nocturnal sleep, daytime functioning, mood, and vigor. The subjects were 14 elderly residents of continued-care retirement facilities while a similar group of 9 elderly residents served as controls. The group exposed to structured activities had increased amounts of slow-wave sleep and demonstrated improvement in memory-oriented tasks following the intervention. Conversely, no significant changes were noted in the amplitude and phase of the body temperature rhythm or in subjective measures of vigor and mood. These results indicate that short-term exposure to structured social intervention and light physical activity can significantly improve memory performance and enhance slow-wave sleep in older adults without alterations to the circadian phase or amplitude of body temperature. This is the first report to demonstrate that low intensity activity in an elderly population can increase deep sleep and improve memory functioning. The high degree of interest in these activities paired with the simple nature of the tasks makes this a potentially practical intervention which can be adapted for both community dwelling and assisted-living elders.

Key words: Aging; aged; sleep; cognitive performance; alertness; EEG; memory recall

INTRODUCTION

THE CIRCADIAN SYSTEM PLAYS AN IMPORTANT ROLE IN ESTABLISHING TEMPORAL COORDINATION among a variety of biochemical, physiological, and behavioral variables while maintaining their synchronization to predictable changes in the environment.[1,2] As a result, spontaneous or experimental disturbances of circadian rhythmicity have been shown to affect human health, safety, and productivity resulting in considerable cognitive impairment, mood alteration, and sleep disruption.[3-6] Characteristic age-related changes in circadian rhythms, such as alterations in the period, phase, amplitude, and precision of both behavioral and physiological rhythms have been shown to occur with advanced age.[7-13] Likewise, the consequences of disrupted circadian rhythmicity, such as sleep disturbances and impaired daytime performance, can also become more pronounced with age.[7,14]

In humans, the most widely acknowledged consequence of age-related changes of circadian rhythms is this disruption of sleep and the prevalence of phase-related sleep disorders in the elderly.[7,12,15-20] The sleep/wake cycle in old age is characterized by fragmented and shallow nocturnal sleep with a marked reduction in slow-wave activity along with daytime sleepiness and an increased number of naps.[21] Sleep disturbances become particularly prominent in elderly residents of assisted living facilities and in patients with dementia.[21,22] Additional factors, such as the lack of professional activities, reduced mobility, and limited social interactions, may result in lower levels of exposure of older persons to light, physical activity and social stimuli which are important synchronizing agents (zeitgebers) for the human circadian system.[8,10,23-25] Age-related changes in the circadian system and decreased exposure to external zeitgebers raises the possibility that exposure to strong environmental and behavioral synchronizing agents may improve sleep and increase the level of daytime functioning in the elderly. Indeed, the results of several studies now indicate that scheduled exposure to bright light can improve sleep and normalize circadian phase in older adults.[11,17,26] However, few attempts have been made to determine if scheduled social and physical activity can have a therapeutic effect on sleep and rhythmicity in the elderly.[27-29] The aim of the present study was to examine the effects of combined schedules of social and physical

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Accepted for publication August 1999

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activity on overt circadian rhythmicity, nocturnal sleep and daytime mood, vigor, and neuropsychological performance in elderly residents of retirement communities.

METHODS

Participants in the activity group consisted of nine women and five men between the ages of 65 and 92 years (75.2±2.6) (mean±S.E.M.). Six women and three men between the ages of 66 and 92 years (71.2±2.6) served as the control group. All subjects had no unstable or acute medical conditions, normal to mildly depressed mood, none to mild dementia (Mini-Mental Status Examination score >24), no major psychiatric illness based on DSM-III-R criteria, were not taking hypnotic or psychoactive medications and all were independent in activities of daily living. Written consent was obtained from all participants and the research protocol was approved by the Institutional Review Board of Northwestern University. The activity protocol consisted of a seven-ten-day baseline period followed by 14 continuous days of exposure to structured social and physical activities between 09:00 and 10:30 in the morning, and 19:00 and 20:30 in the evening. Two identical 48-hour periods of physiological monitoring and neuropsychological testing were conducted during the last two days of the baseline period and immediately after the completion of the 14-day intervention period, respectively. The control protocol was identical except that during the 14-day intervention period the participants did not alter their usual social or physical activities.

Procedures for Structured Exposure to Physical and Social Activity

Each activity session was performed at the homes or apartment complexes of the participants with a group of at least three people. Activity included a sequence of 10 minutes of stretching and a 20-minute period of light physical activity (walking, stationary upper and lower body exercises). This initial activity period was followed by 30 minutes of seated social interaction (usually spent playing board and/or card games). The final 25 minutes of the intervention consisted of an active game, such as ball catching, croquet or dancing, and concluded with five minutes of cool-down stretching exercises. New games and exercises, incorporating entertaining or competitive elements, were introduced regularly during the structured activity routine to maintain the motivation and interest of the participants.

Measurements of Activity and Light Level

The Actillume system (Ambulatory Monitoring Inc, Ardsley, NY) was worn by all participants on the wrist of their non-dominant hand and used to record the activity-rest cycle and light exposure during the entire protocol. Activity counts were stored at one minute intervals while light intensity measurements were made every five minutes. In addition, all participants were asked to keep a daily log of their wake-up times, bedtimes, nighttime awakenings, daytime naps, meals, social, and physical activities.

Mean 24-hour profiles of wrist activity and light exposure in 30-minute bins were calculated for each participant during the baseline and the intervention period and further used to derive the corresponding activity and light exposure profiles for the entire group. The mean levels of wrist

Table 1—Sleep times and percentages for the activity treatment and control groups during the entire night. Values are reported as means±S.E.M. * - $p<0.01$

	Activity Group				**Control Group**			
	baseline[1]		**post-treatment**		**baseline[1]**		**post-treatment**	
	mean	**(SEM)**	**mean**	**(SEM)**	**mean**	**(SEM)**	**mean**	**(SEM)**
TST (min)	337.0	(22.5)	345.5	(19.2)	337.6	(19.5)	325.8	(15.7)
WASO (min)	76.0	(9.4)	61.9	(9.5)	66.9	(9.6)	96.6	(16.3)
SOL (min)	33.0	(15.4)	19.0	(6.0)	23.6	(9.3)	29.6	(7.9)
stage 1 (min)	50.7	(4.6)	53.5	(7.7)	45.7	(6.8)	48.8	(8.2)
stage 2 (min)	204.0	(12.5)	196.2	(10.5)	193.0	(16.1)	180.4	(10.2)
SWS (min)	27.0	(5.5)	39.3	(8.2)	36.9	(2.0)	34.0	(3.1)
REM (min)	55.4	(7.5)	56.5	(5.5)	61.9	(7.9)	62.6	(5.9)
stage1 % of TST	15.1%	(1.1%)	15.2%	(1.8%)	13.8%	(2.3%)	14.5%	(1.9%)
stage 2% of TST	61.0%	(1.5%)	57.0%	(1.6%)	56.9%	(2.6%)	55.3%	(1.9%)
SWS % of TST	8.1%	(1.4%)	11.4%	(2.2%)*	11.2%	(1.0%)	10.9%	(1.4%)
REM % of TST	15.7%	(1.5%)	16.4%	(1.1%)	18.1%	(1.8%)	19.3%	(1.8%)
sleep maintenance	81.2%	(2.7%)	84.8%	(1.8%)	83.1%	(2.3%)	77.6%	(3.1%)

[1] No statistical difference was noted between the baseline values for both groups.

activity from 09:00 to 10:30 in the morning and 19:00 to 20:30 in the evening during the last five days of the structured routine were used to assess the individual impact of the experimental intervention and corroborate that the intervention successfully elevated activity levels.

Polysomnography

Polysomnographic monitoring of nocturnal sleep was performed during the two nights at the end of the baseline period and after the intervention period. A portable sleep recording system (Digitrace Care Services, Boston, MA) was used to obtain electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG) data from the participants in their own rooms at the continued-care retirement facilities. In order to screen for sleep disorders, such as sleep apnea and periodic leg movements during sleep, a full polysomnogram (including airflow, respiratory effort, electrocardiogram, pulse oximetry, and leg EMG electrodes) was performed on all participants during the first night of baseline sleep monitoring.

The polysomnographic sleep records were evaluated in 30-second epochs by two independent scorers who were blinded to the type of intervention. Sleep stages were scored according to the Rechtschaffen and Kales criteria.[30] During both the baseline and post-treatment sleep recording sessions, the first night was regarded as an adaptation and screening night while the second night was used to evaluate sleep. The first night of sleep recording was used in only one activity and two control participants when the second night's data was unavailable due to technical problems.

Neuropsychological Performance and Mood Assessment

Participant's mood, vigor, and performance on testing days were assessed every 90 minutes between 08:00 and 20:00. Tests were adapted from a design by Monk et al.[31,32] and supplemented with a version of the Automated Neuropsychological Assessment Metrics (ANAM) developed by NASA.[33] Each session included a series of computerized tests which measured accuracy and reaction time

Table 2—The top portion of the table shows mean throughput values for each group during the baseline testing period. The column labeled p-value demonstrates that there were no significant differences between the activity and the control group for any test during the baseline period. Baseline values were analyzed by repeated measures ANOVA with protocol (activity versus control) as a between-subjects factor and time point as a repeated factor. The lower portion shows the mean percent improvement for each group on individual tests following experimental intervention.

BASELINE TESTING VALUES

	Activity Group		Control Group		
test name	**mean**	**(SEM)**	**mean**	**(SEM)**	**p-value**
1 procedural memory	14.7	(1.8)	15.7	(2.2)	0.258
2 sternberg 2	12.7	(2.4)	14.0	(2.9)	0.281
3 sternberg 4	11.7	(2.0)	12.7	(2.6)	0.290
4 mathematical processing	3.4	(1.0)	3.9	(0.9)	0.332
5 running memory	13.5	(2.0)	15.4	(2.9)	0.083
7 spatial processing	3.6	(0.9)	3.8	(0.9)	0.737
8 symbol copy	112.6	(25.3)	122.8	(40.0)	0.444
9 digit symbol	44.1	(13.8)	46.2	(15.1)	0.723
10 e-search	32.2	(7.5)	33.6	(13.1)	0.774
11 m before c	15.6	(7.0)	17.6	(10.9)	0.161

CHANGE IN THROUGHPUT FOLLOWING INTERVENTION

	Activity Group		Control Group		
test name	**mean**	**(SEM)**	**mean**	**(SEM)**	**p-value**
1 procedural memory	5.8%	(1.3%)	-0.1%	(2.1%)	0.029
2 sternberg 2	11.4%	(3.0%)	4.1%	(2.1%)	0.062
3 sternberg 4	7.7%	(1.8%)	4.9%	(2.7%)	0.409
4 mathematical processing	15.9%	(3.2%)	11.8%	(2.9%)	0.359
5 running memory	12.7%	(2.6%)	6.1%	(2.3%)	0.073
7 spatial processing	7.3%	(1.8%)	6.8%	(3.4%)	0.491
8 symbol copy	14.9%	(8.3%)	2.5%	(2.2%)	0.167
9 digit symbol	17.1%	(6.6%)	11.9%	(4.1%)	0.516
10 e-search	10.7%	(3.4%)	11.3%	(2.3%)	0.885
11 m before c	18.5%	(5.8%)	20.5%	(5.5%)	0.810

for measures of procedural and running memory, mathematical reasoning, spatial processing, and Sternberg two- and four-item memory tasks. In addition, a set of paper and pencil tests (symbol copying, digit-symbol substitution, visual search, and a two-letter logical reasoning task) was used to assess fine motor speed and coordination, verbal reasoning, attention, visual scanning, and visual-motor efficiency and integration. A throughput measure for each test was calculated by taking the number of correct test answers, dividing that by the average reaction time for each answer and multiplying the result by 100. Each testing session ended with the administration of eight visual analog scales (VAS) for the assessment of subjective vigor (alertness, sleepiness, weariness, amount of effort) and mood (happiness, sadness, calmness, tenseness). The corresponding scores were then used to calculate measures of global vigor and affect.[34] In order to minimize the effects of practice on the assessment of mood and performance, all participants engaged in training sessions during the baseline period. Mood, vigor, and performance scores, collected during each two-day testing period, were compared for overall treatment effects as well as during individual testing periods.

Core Body Temperature

Core body temperature of each participant was recorded continuously at one-minute intervals for 48 hours using a rectal thermometer (YSI style 4491E, Yellow Springs, OH) connected to the Mini Logger system (Mini-Mitter Inc, Sun River, OR). Temperature was recorded during the last two days of the baseline period and during the two days after the 14-day activity or control intervention period. The data from each 48-hour record of core body temperature were averaged across the two days to produce a single 24-hour profile with 288 five-minute bins. Using a robust locally-weighted regression procedure[35] each of these 24-hour profiles was quantitatively described by a best-fitting curve. The phase of the 24-hour temperature rhythm was defined as the timing of the minimum of the best-fitting curve (nadir). Temperature amplitude was calculated to be 50% of the difference between the highest and the lowest fitted value.

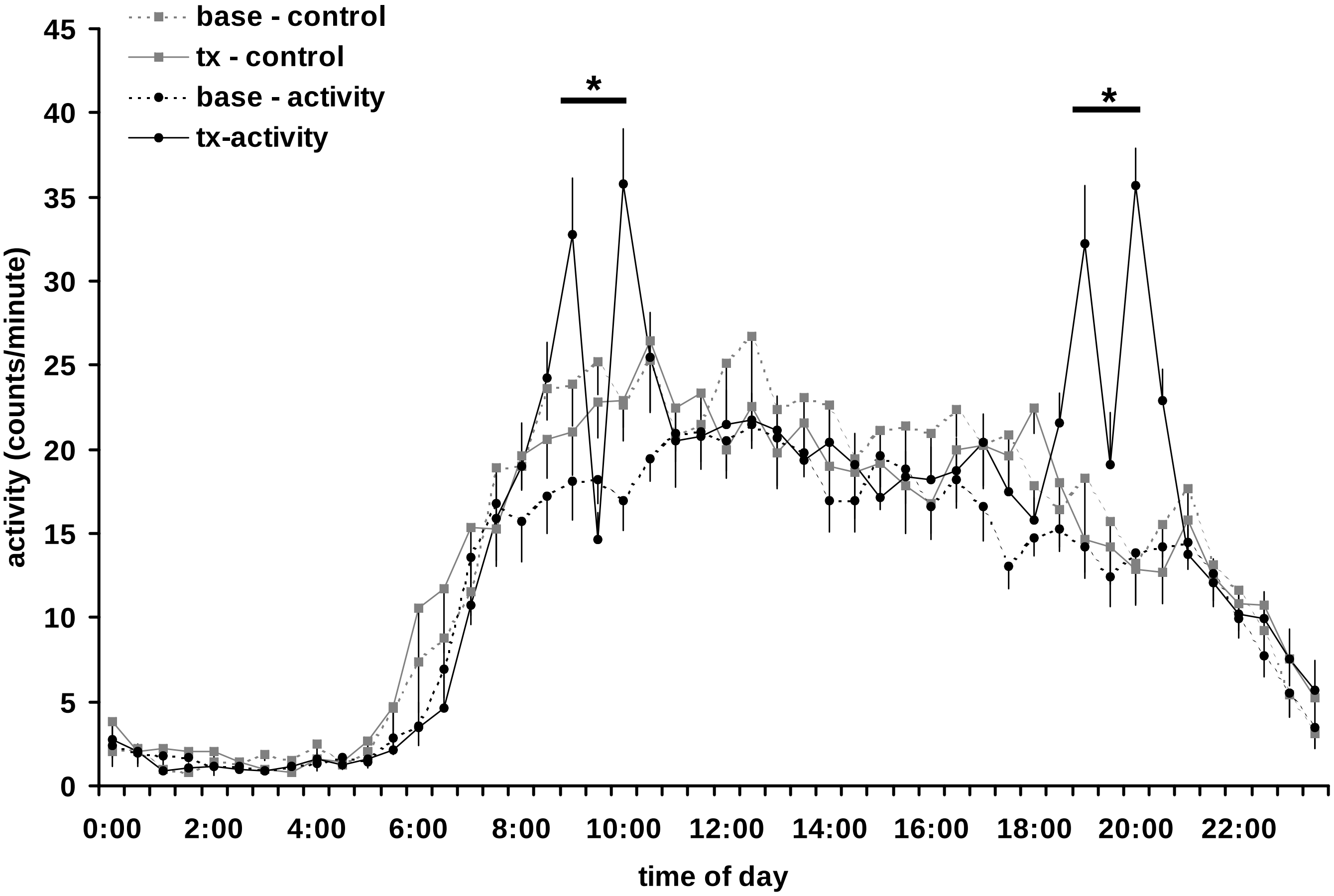

Figure 1— Average daily activity for 13 activity protocol (circles) and 9 control (squares) participants. Wrist activity was averaged in half-hour bins over the last five days of the baseline period (dotted lines) and during the last five days of the intervention protocol (solid lines). * -indicates a significant ($P<0.05$) elevation in overall activity during that time in the group undergoing the activity treatment protocol.

Analysis and Statistical Methods

To analyze actigraphy, light exposure, sleep variables, performance tests, core body temperature, and mood/vigor ratings, we used repeated measures ANOVA (rm-ANOVA) with one between-subjects factor, protocol, and two repeated factors— day of measurement and time point. Preplanned post-hoc comparisons were treatment (average of Day 1 and Day 2 vs. average of Day 3 and Day 4) for each protocol group as well as treatment between protocols. To put measures from different tests on the same scale, we calculated the percent change from baseline for each time point for each person. On these percentages, we used rm-ANOVA with one between-subjects factor (protocol) and one repeated factor (time point). In some instances, such as with SWS parameters and certain neuropsychological tests, unplanned comparisons were implemented due to new information that became available during the conduct and analysis of the studies.

RESULTS

Effects of the Experimental Intervention on Wrist Activity and Light Exposure Profiles

The mean daily actigraphic records from 13 activity and 8 control participants are shown in Figure 1. Similar patterns of wrist activity level were seen during the baseline period in both activity and control groups. During baseline conditions, activity level was significantly higher in the morning (09:00 to 10:30) compared to the evening (19:00 to 20:30) (AM: 20.0±1.3 counts/min; PM: 14.3±1.3 counts/min, t[21]=3.820, p=0.001) for both the control and activity groups. We opted to look at only these time points because of the predominant effects of the activity intervention. Participation in the activity protocol resulted in a significant increase in wrist activity counts in the morning and evening sessions. There was an increase in activity levels by more than 50% over baseline (17.7±1.4 counts/min; post-tx: 27.7±2.0 counts/min, t[13]=5.801, p<0.001) in the morning session and a greater than 100% increase over the

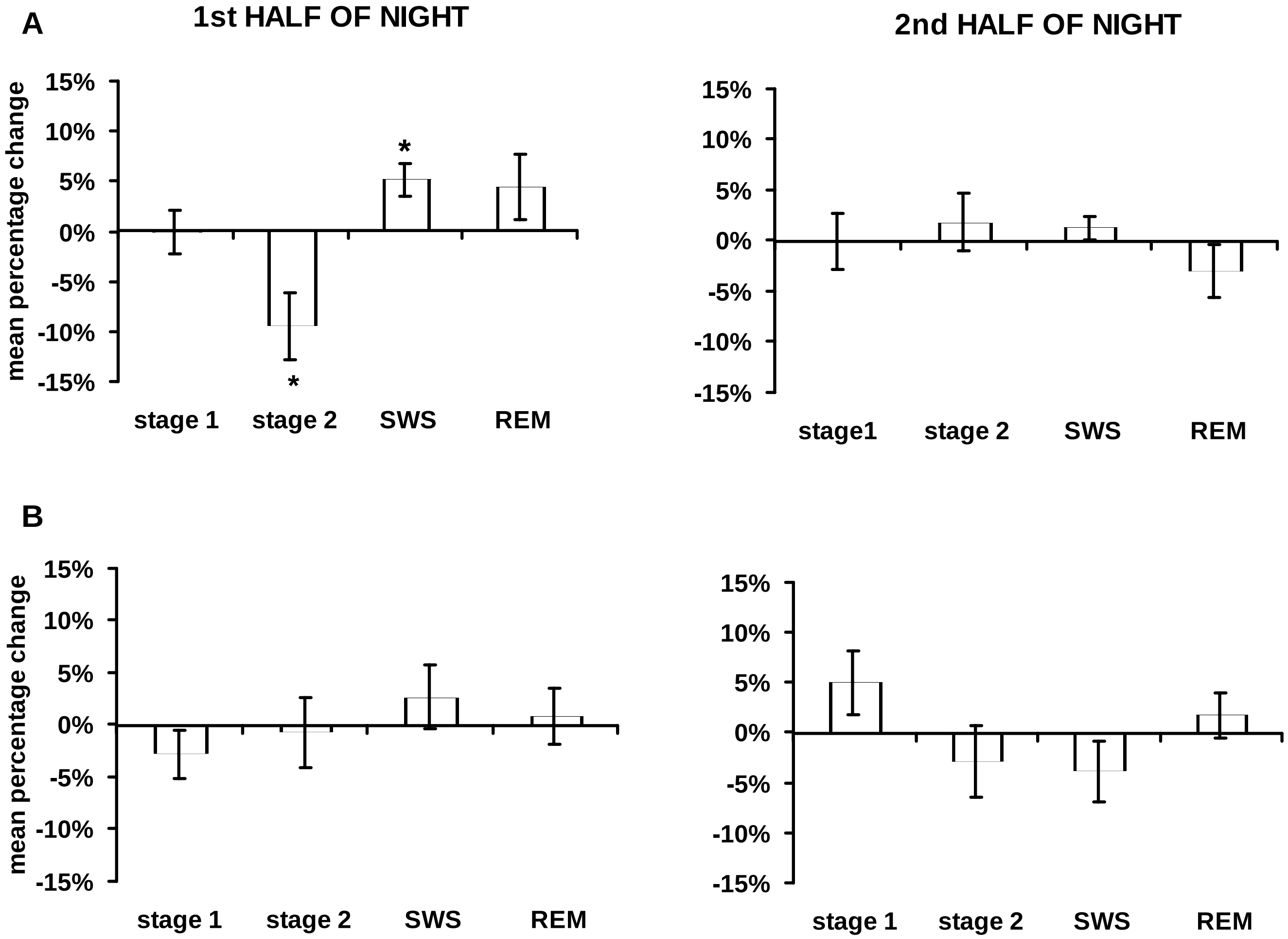

Figure 2—Effects of structured social and physical activity on polysomnographic measures of sleep stages in the first and second half of the night for activity (a) and control (b) groups. Bars represent mean ± S.E.M. change from baseline. * - indicates P<0.05

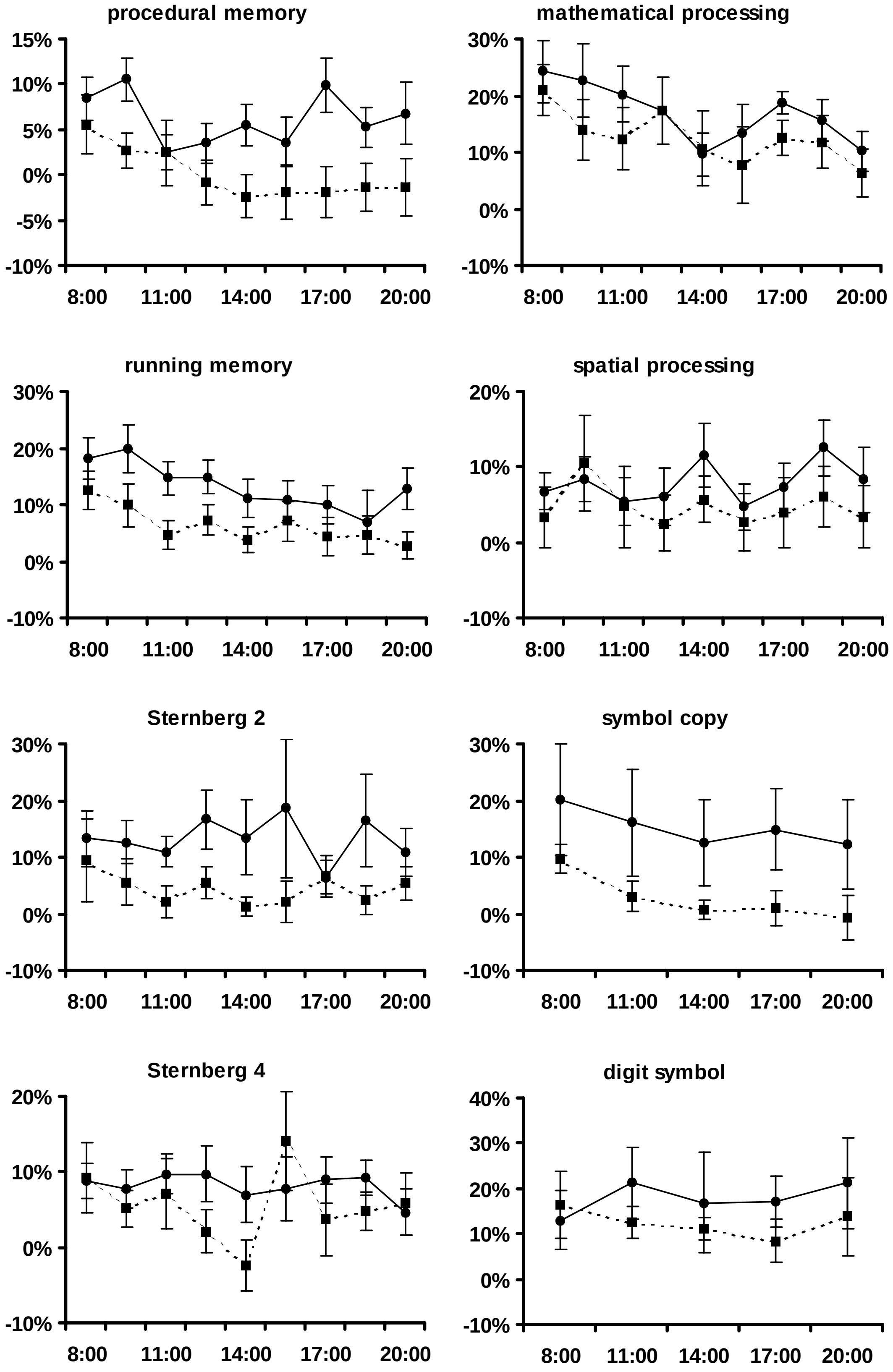

Figure 3—Effects of structured social and physical activity on eight measures of neuropsychological performance for the activity group (solid line) and control group (dashed line). The y-axis indicates the percentage improvement over baseline throughput values of correct answers (100 X accuracy/reaction time) for each group at each testing period. The x-axis indicates the time of day that the testing session occurred.

corresponding evening baseline period (13.5±1.4 counts/min; post-tx: 29.0±2.1 counts/min, t[13] = 7.993, p<0.001). Whereas, in the control group, activity levels remained unchanged throughout the protocol. Light exposure in both the control and activity groups remained unchanged throughout the study.

Effects of Structured Activity on Sleep Parameters

Analysis of sleep stages across the entire night was possible in subjects who yielded complete polysomnographic records (12 of the 14 activity and 8 of the 9 control participants). Data was unavailable from three subjects due to equipment difficulties. Using a between groups comparison we found no significant differences between the baseline activity and baseline control values. There was a significant increase in the amount of sleep time spent in slow-wave sleep (SWS) (stages 3+4) for subjects participating in the activity protocol (8.1±1.4% baseline vs. 11.4±2.2% post treatment, f[1,11]=12.099, p=0.005) after the 14-day intervention, while in the control group the amount of SWS was unchanged. Other sleep measures revealed no significant difference between baseline and post-treatment periods for either group (Table 1).

Because SWS occurs primarily in the first half of the night, it was decided that sleep parameters should be divided and analyzed for each half of the sleep period independently. Here, the increase in SWS is even more pronounced during the first half of the night (Figure 2a). For participants receiving structured social and physical activity SWS significantly increased occupying 11.8±2.0% of the total sleep time during baseline conditions and increasing to 17.0±3.1% after the intervention period (f[1,11]=9.896, p=0.009). This amounts to an average of ten additional minutes of SWS after treatment intervention (20.7±4.2 min baseline vs. 30.5±5.7 min post treatment). This increase of SWS was primarily due to an accompanying significant decrease in stage 2 sleep in this group (63.5 ±2.0% baseline vs. 54.1±2.8% post treatment, f[1,11]=8.105, p=0.016). During the second half of the night there were no sleep changes noted. Participants in the control group did not exhibit significant changes in any of the sleep parameters when analyzed during either half of the night (Figure 2b).

Effects of Structured Activity on Daytime Levels of Neuropsychological Performance

A direct comparison of the percentage improvement in throughput values showed that the scores for the activity group were significantly greater overall on the procedural memory task (t-test with separate variances T[13.8]=2.429, P=0.029). While none of the other tests showed significant improvement by a direct between group comparison, in all cases except the e-search task, the mean percentage improvement was greater in the activity than in the control subjects (Table 2 lower panel). This was not due to differences in baseline values (Table 2 upper panel). The improvement in procedural memory led us to further examine the other memory tasks in the protocol. When results from all four memory-specific tests (procedural memory, running memory, Sternberg-2, and Sternberg-4) are combined in a repeated measures ANOVA with one betwee subjects factor, protocol, and three repeated factors (test, time of day and time point), we find that the activity group is significantly improved over the controls (f[1,21]=5.024, p=0.036). Improvement over baseline for eight of the ten tests is shown in Figure 3.

Effects of Structured Activity on the 24-h Profile of Core Body Temperature

Ten of the fourteen activity participants and seven of the nine control participants contributed data series of sufficient quality to reliably estimate the phase and amplitude of the circadian rhythm of body temperature both before and after the experimental intervention. The experimental intervention did not alter the amplitude (0.40±0.04 °C during baseline vs. 0.35±0.04 °C post treatment) or the phase of the core body temperature rhythm. The mean nadir of evening body temperature occurred at 0330 ± 0.40 h during baseline and 0315±0.31 h during the post treatment period. The control group likewise demonstrated no significant change in either the amplitude (0.38±0.05 °C baseline vs. 0.36±0.04 °C post treatment) or timing of the evening nadir of the temperature rhythm (0325±0.50 h baseline vs. 0418 ±0.25 h post treatment). Exposure to structured activity did not alter the phase or amplitude of the temperature rhythm in any of the subgroup of older adults who had a temperature nadir occurring before 03:00.

Effects of Structured Activity on Subjective Measures of Mood and Vigor

No significant changes in the daytime profiles of global vigor or global affect were detected following the completion of the 14-day structured activity protocol in either the activity or the control group. However, all of the participants in the activity group expressed that they enjoyed the social and physical activity periods and that it had an overall positive effect on their sense of well-being. Eleven out of the fourteen subjects in the activity group offered to participate in this type of a study again whereas, only three out of the nine in the control group volunteered.

DISCUSSION

These are the first results to show that daily low-intensity exercise paired with structured social interaction can significantly increase or enhance slow-wave sleep and improve daytime memory function in an elderly population. Evidence from a series of animal and human studies indicates that both social stimuli and physical activity are effective synchronizing agents for the mammalian circadian system.[27,36,37] Although little is known regarding the effects of social activity on circadian rhythmicity in older people, there is some evidence that physical exercise can alter circadian rhythmicity. In healthy adults physical exercise in the form of aerobic training resulted in a small phase delay and an increase in the amplitude of the circadian rhythm of core body temperature.[27,38] In contrast, exposure to a morning and evening schedule of structured social and mild physical activity in the present study did not significantly alter the phase or the amplitude of the circadian rhythm of body temperature. These differences may be due to the timing of the intervention and/or the intensity of physical exercise in the two studies. The level of physical activity in our study was mild and did not at any time reach the intensity achieved with aerobic training.

In addition to the effects of exercise on circadian rhythms, results from a few studies performed in young subjects indicate that aerobic training and acute exercise have positive effects on sleep homeostasis and can increase the amount of slow-wave sleep.[10,23,39] In contrast, the relationship between physical exercise and sleep in the elderly has received less attention.[40,41] Similar to our present finding, Vitiello et al. found that long-term aerobic training in healthy older adults can improve certain sleep parameters and increase the total amount of slow-wave sleep.[28] In Vitiello's study of healthy older people, a selective increase in slow-wave sleep was seen only in the aerobic training group but not in the stretching/flexibility exercise control group, suggesting that the increase in slow-wave sleep may be related to the intensity of physical activity.[28] In our study, an increase in slow-wave sleep was seen following exposure to more modest levels of physical activity. However, because the mild level of physical activity was coupled with enhanced social activity, the effects on sleep may be due to the effects of social activity or the combination of the two types of activities. Recently, a study by King et al.[29] indicated that a group of older adults participating in moderate intensity exercise over a 16- week period reported subjective improvement of sleep quality. Despite the apparent beneficial effects of physical activity on sleep in healthy older adults, improvements in subjective and actigraphy based sleep measures were not seen in nursing home residents after exposure to increased physical activity.[42] In our study, improvement in sleep was detected in the polysomnographic records, but not in the actigraphy records.

In addition to improvements in slow-wave sleep, enhancement of physical and social activities was accompanied by improvement in measures of neuropsychological performance. It is interesting that the most robust effects were seen in the four memory tests (mainly working memory), which are highly dependent on attention. The mechanism(s) by which exposure to social and physical activity enhances performance is unknown, although it has been postulated that increased blood flow to the brain during mental and physical exercise improves neuronal function.[43-45] It is also possible that increasing slow-wave sleep results in improved daytime attention and therefore performance. We suspect that due to the small sample size, the protocol X treatment interaction did not show significance. However, because the activity group steadily demonstrated a consistently greater improvement in neuropsychological tasks and sleep parameters than did the control group,a larger sample size may yield statistical significance demonstrating that the activity group improvement was due to more than just practice effects.

While these results demonstrate that short-term, relatively low levels of physical activity combined with social interaction have positive effects on sleep and daytime functioning in older adults, the relative contribution of physical exercise and psychosocial activation in reinforcing slow-wave sleep and improving neuropsychological functioning remains unknown. A better understanding of the role of the physical vs. social activity components, as well as the optimal timing, intensity, and duration of such interventions, will be important in the design of practical interventions to improve sleep and neuropsychological performance in the elderly.

ACKNOWLEDGMENTS

We wish to thank our volunteers from the Presbyterian Home and Council for Jewish Elderly for their interest and participation in this study. We would also like to thank Alexander N. Moffett for his help in editing this manuscript. This work was supported by an NIH grant PO1-AG-11412 and the Brookdale National Foundation.

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