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Potassium Affects Actigraph-Identified Sleep

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Summary: The present study examines the effects of potassium supplementation on sleep quality and phase, as indirectly inferred from wrist actigraphy and sleep logs, in normal young males on a low-potassium diet. A randomized, double-blind, placebo-controlled, counterbalanced crossover design compared 1 wk of oral potassium chloride supplements (96 meq/day) to 1 wk of identical placebo capsules. Outcome measures were taken from sleep logs and wrist actigraphy. Sleep was indirectly inferred from wrist-actigraph data using a computer algorithm. Potassium supplementation significantly delayed sleep-log-identified *Bedtime* ($p < 0.001$). Potassium reduced *Sleeping Interval* for both sleep-log ($p < 0.01$) and wrist-actigraph ($p < 0.1$) data. Potassium significantly increased actigraphic *Sleep Efficiency* ($p < 0.05$) due to a reduction in actigraphic *Wake after Sleep Onset* (*WASO*) ($p < 0.05$). No effect of potassium on actigraphic sleep phase was observed. Side effects were minimal and not significantly different between treatment conditions. The results may indicate an improvement in sleep consolidation with potassium supplementation. Further studies using standard polysomnography are required to define potassium's effects on human sleep. **Key Words:** Potassium—Sleep—Activity—Human—Actigraph.

High ambient potassium levels have been shown to shorten the period of circadian rhythms in a variety of organisms. For example, potassium shortens the period of the bioluminescence rhythm in *Gonyaulax* (1) and the leaf movement rhythm in *Oxalis regnalli* (2). The circadian rhythm in optic nerve firing rate is accelerated by high potassium levels and phase shifted by potassium pulses in *Aplysia* (3,4). Similar results were obtained in *Bulla* (5). More recently, Klemfuss and Kripke (6) observed that, in hamsters entrained to 4-hr light pulses on a L:D 4:20 schedule, activity onset occurred about 1 hr earlier in animals on a high-potassium compared to those on a standard diet. The effect on tau was equivocal in free-running hamsters, and it was demonstrated that an enhanced phase-advance portion of the phase–response curve was mainly responsible for the results (7). It seemed possible that human rest/activity might be similarly affected by dietary potassium.

Little is known about the effects of dietary mineral nutrients on human sleep quality. Vitiello et al. (8) noted prolonged sleep latencies and poorer sleep efficiency with a low-sodium diet compared to a standard diet. They hypothesized that the poor sleep was associated with increased sympathetic activation. Clinically, both hypocalcemia and hypomagnesemia are associated with insomnia (9). We are not aware that effects of dietary potassium on sleep quality have been previously explored.

The purpose of this study was to investigate the effects of varying dietary potassium intake in healthy young males on sleep phase and quality, as indirectly inferred from sleep-log and wrist-actigraph data.

METHODS

Subjects were nine healthy, paid, male volunteers 18–33 yr of age. Each received a low-potassium diet (about 40 meq/day) and a potassium-free multivitamin supplement for 17 days, constituting three equilibration days and a 2-wk experimental period. A randomized, double-blind, placebo-controlled, counterbalanced crossover compared 1 wk of 96-meq/day oral microencapsulated potassium chloride supplements (Micro-K, A. H. Robins Corporation, Richmond, VA) to 1 wk of identical placebo capsules, on a "tid with meals" schedule. On day 7 of each experimental week, blood for serum potassium analysis was drawn between 11:30 a.m. and 12:30 p.m., prior to the lunch-

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time dosing. A questionnaire about side effects was completed at the end of each experimental week. Subjects were asked to guess which week they were on potassium at the end of the study. Subjects wore a Motionlog actigraph on their dominant wrist for the 2 wk, kept sleep logs and were asked not to nap. To allow circadian phase shifts to occur, only the last four nights of each experimental week were analyzed.

Sleep scoring. Sleep-log data were interpreted for *Bedtime, Sleep Offset* and sleep-log *Sleep Interval* (*Sleep Offset* minus *Bedtime*). Sleep and wake were indirectly inferred from actigraph data using the automated computer scoring method of Cole and Kripke (10). Actigraphic *Sleep Onset* was defined as the first full-minute computer-inferred sleep after the identified bedtime. *Sleep Latency* was defined as the interval between the sleep-log-identified *Bedtime* and the actigraphic *Sleep Onset*. Actigraphic *Sleep Offset* was defined as the last minute of computer-inferred sleep in a sleep period. It was determined visually by a blind rater, and did not necessarily correspond to the sleep-log *Sleep Offset* time. Actigraphic *Sleep Interval* was defined as actigraphic *Sleep Offset* minus *Sleep Onset*. Actigraphic *Total Sleep* was defined as the total actual time the computer inferred sleep between actigraphic *Sleep Onset* and *Sleep Offset*. Actigraphic *Wake after Sleep Onset* (*WASO*) was defined as the time spent awake over the same interval. Actigraphic *Sleep Efficiency* was defined as the actigraphic *Total Sleep* divided by the actigraphic *Sleep Interval*. Sleep-log and computer-scored actigraph data were analyzed separately with analyses of variance.

Naps. The sleep log identified only two naps in 48 experimental days. The automated actigraphic scoring method inferred naps of greater than 5 min continuous duration on less than 5% of experimental days. However, brief actigraphic naps of 1–5 min duration were scored on many days. Actigraphic naps were analyzed separately for total minutes asleep outside the actigraphic *Sleep Interval* (as defined above) and for evening nap time (between 6:00 p.m. and sleep-log *Bedtime*). The mean computer-inferred daily napping from actigraph data was compared between conditions by analyses of variance.

RESULTS

Serum pottassium levels were 4.4 ± 0.4 and 4.1 ± 0.25 meq/l (mean ± SD) for potassium and placebo intervals, respectively ($p < 0.05$, one-tailed, paired t test). All values were within the normal range of 3.5–5.0. Five subjects guessed correctly and four incorrectly which week had active medication (ns, chi square). Only one subject reported significant side effects (mild abdominal cramping and moderate weakness) attributable to potassium. Due to technical problems, actigraph data for only six subjects were available for analysis (four placebo first, two potassium first).

Sleep-log and computer-scored actigraph data are presented in Table 1. Potassium supplementation delayed sleep-log-identified *Bedtime* by about 25 min ($p < 0.001$). *Sleep Interval* by sleep log was significantly shortened, but this result was confounded by a significant treatment order × treatment interaction ($p < 0.05$). A trend toward a decrease in actigraphic *Sleep Interval* ($p < 0.1$) with potassium supplementation was also observed using the actigraphic method. There was an increase in actigraphic *Sleep Efficiency* ($p < 0.05$) with potassium supplementation. This corresponded to a decreased actigraphic *WASO* with potassium supplementation ($p < 0.05$) rather than to changes in actigraphic *Total Sleep Time* (ns). No significant effect of potassium was observed in actigraphic *Sleep Onset* or *Sleep Offset* timing. After actigraphs were hand-scored by a blind rater, results were in the same direction as those reported for computer-scored data, but were not statistically significant.

There was no significant difference between potassium and placebo conditions in time spent asleep during computer-inferred actigraphic naps. Overall actigraphic naptime was about 5% of actigraphic *Total Sleep Time*. Actigraphic evening naps were less than 2.5%. Analyses adding naps to total sleep time did not alter the results.

DISCUSSION

Potassium intake in this study was artificially limited to about 40 meq/day, on average, for control weeks, and was then supplemented to about 140 meq/day for potassium-treatment weeks. These intakes correspond to the 25th and 90th percentiles of normal daily potassium intake in this age-group, respectively (11); that is, at all times potassium intakes were within the normal range. Serum potassium levels remained within normal limits. Hence, the apparent changes in sleeping habits observed in this study could correspond to variations within the normal population in dietary potassium effects on sleep.

A very important methodologic issue is whether a change in actigraph-identified sleep may presume a change in actual sleep. There is a strong relationship between nocturnal sleep EEG and activity level as assessed by wrist actigraphy, especially in healthy young adults (10,12–15). However, it is conceivable that sleep in our subjects may have become more restless on the low-potassium diet, without an increase in actual arousals. Alternatively, the relationship between sleep and wrist activity might be lowered in persons with sleeping difficulty. This seems unlikely to explain the

TABLE 1. *Sleep-log and actigraph data under placebo and potassium conditions*[a]

	Actigraph		Sleep log	
	Placebo	Potassium	Placebo	Potassium
Sleep Onset[b]	0.3 ± 0.9	0.7 ± 1.0	−0.24 ± 1.00	0.17 ± 1.06**
Sleep Offset[b]	7.9 ± 1.5	7.6 ± 1.2	7.07 ± 1.17	7.11 ± 1.08
Sleep Interval (min)	440 ± 83	412 ± 66†	439 ± 56	416 ± 52**[c]
Sleep Efficiency (%)	89.2 ± 5.1	93.8 ± 3.2*	—	—
Sleep Latency (min)	27.9 ± 21.4	16.6 ± 9.9	—	—
WASO (min)	47.4 ± 20.9	25.8 ± 15.0*	—	—
Total Sleep (min)	394 ± 80	386 ± 58	—	—

[a] Potassium main effects versus placebo: †$p < 0.1$, *$p < 0.05$, **$p < 0.001$.
[b] Sleep times in decimal hours past midnight. Actigraphic sleep was indirectly inferred from wrist actigraph data using a computer algorithm (see text).
[c] Significant order × treatment interaction ($p = 0.04$).

current results. Using our automated system, agreement rates between actigraph- and sleep EEG-identified sleep epochs are prospectively very similar, on the order of 88–91%, among normals, psychiatric patients and a small number of elderly persons and insomniacs (Cole et al., in preparation). Furthermore, it is unlikely that such interindividual differences in sleep–activity relationships would be nearly as important in a within-subjects crossover design. Nonetheless, one cannot be certain that potassium affects EEG sleep without standard polysomnography.

There was an improvement in actigraphic *Sleep Efficiency* when the low-potassium diet was supplemented with potassium capsules. This was accompanied by a significant *decrease* in actigraphic *Sleep Interval* by sleep log, though only a trend was apparent in the actigraph data. Reduced actigraphic *WASO* was observed with potassium supplementation, rather than any change in actigraphic *Total Sleep*. This finding might be interpreted as either a decreased actigraphic *Sleep Interval* leading to decreased *WASO*, or as improved consolidation of sleep (decreased *WASO*) with potassium supplementation causing shorter *Sleep Intervals*.

Circadian theory suggests possible mechanisms for the findings of this study. Klemfuss (unpublished) has observed a decreased duration of the wheel-running activity band in free-running hamsters on a high-potassium diet. This might imply that potassium causes tighter coupling between morning and evening components of the circadian oscillator in these animals (16). Activity consolidation in a nocturnal animal might be analogous to sleep consolidation in a diurnal animal, such as man. Alternatively, an improved amplitude of the normal daily potassium rhythm might induce a greater amplitude in daily rest–activity cycles, hence, improved consolidation of sleep. Such explanations remain highly speculative.

The data might imply that a low-potassium diet induces sleeping difficuty, which can then be corrected by supplemental potassium. Nonetheless, potassium intake in the placebo condition still corresponded to the 25th percentile of normal intake for young males. These subjects were recruited as regular, good sleepers, yet the placebo sleep efficiencies inferred from wrist activity measurements are similar to those reported in wrist actigraph data from insomniac populations (17). It is possible that addition of potassium in persons with already high potassium intake would result in no additional benefits. Our findings may also be of importance in other metabolic abnormalities, such as diuretic-induced hypokalemia.

Potassium supplementation showed little consistent effect on circadian sleep phase. Although self-selected *Bedtimes* showed a highly significant delay according to sleep logs, the similar delay in actigraphic data was not significant. Furthermore, a delay in bedtime may be consistent with improved consolidation of the sleep period. Klemfuss used 4 hr of light exposure to explore potassium effects in hamsters (6), whereas young adults may get as little as 15–30 min of bright light exposure per day, at scattered intervals (18,19). Inconsistency in responses of these subjects might thus be related to inconsistent light exposures.

In summary, when a low-potassium diet is supplemented with potassium capsules, apparent sleep consolidation and efficiency, as indirectly inferred by computer algorithm from wrist activity, were improved. No consistent effects on sleep phase were found. Replication of this finding using standard polysomnography is needed before it is certain that potassium intake influences EEG sleep.

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