The influence of circadian rhythms on the temporal features of motor imagery for elderly inpatients

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The influence of circadian rhythms on the temporal features of motor imagery for elderly inpatients

Abstract

Objective: To examine the circadian modulation on motor imagery quality for elderly inpatients to determine the best time-of-day to use motor imagery in rehabilitation activities.

Design: Inpatient rehabilitation clinic.

Setting: elderly inpatients rehabilitation center.

Participants: Thirty-four elderly inpatients. They were hospitalized for diverse geriatric or neurogeriatric reasons. They were able to sit without assistance, to manipulate objects and to walk 10 meters in less than 30 seconds without technical help or with a simple stick.

Intervention: none.

Main outcome measures: The executed and imagined durations of writing and walking movements were recorded 7 times a day (from 9:15 to 16:45 h), at times compatible with the hours of rehabilitation activities. Motor imagery quality was evaluated by computing the isochrony index (i.e., the absolute difference between the average duration of executed and imagined actions) for each trial and each inpatient. The cosinor method was used to analyzed time series for circadian rhythmicity.

Results: Imagined movements duration and isochrony index exhibited circadian modulations, whereas no such rhythmic changes appeared for executed movements. Motor imagery quality was better late in the morning, at approximately 10:18 and 12:10 h for writing and walking, respectively.

Conclusions: Cognitive and sensorimotor aspects of motor behaviors differed in the elderly inpatients. The temporal features of motor imagery showed a clear circadian variation. From a

practical perspective, the present study offers information on an effective schedule for motor imagery in rehabilitation activities with elderly inpatients.

Keywords: Motor imagery quality; isochrony index; aged inpatients; rehabilitation

Introduction

Motor imagery practice is described by cognitive neuroscientists as the mental rehearsal of voluntary motor acts without any overt motor output.[1] Many experimental studies have shown its usefulness in motor learning and rehabilitation.[2-4] The beneficial effect of motor imagery on motor performance can be explained by simulation theory, which posits that imagined and executed actions share common mechanisms[5] and result in similar structural and functional effects. However, motor imagery interventions are not always successful for patients or healthy subjects.[6,7] The efficiency of motor imagery may vary depending on several factors, including motor imagery quality, motor imagery modality, gender and age.[8] In the present experiment, we specifically examined circadian modulation on motor imagery quality in a geriatric hospitalized population to determine the best time-of-day to use motor imagery in rehabilitation activities.

In motor learning and rehabilitation programs, motor imagery practice relies on the subjects' ability to generate motor images.[9-14] Motor imagery questionnaires[15-17] and mental chronometry[18-20] have been used to assess motor imagery ability. Motor imagery questionnaires provide information about the vividness of motor imagery, whereas mental chronometry provides information about the temporal coupling between executed and simulated actions (i.e., the isochrony principle). Some experiments have shown that the temporal congruence between overt and covert actions can vary throughout the day for young healthy participants. Gueugneau and collaborators[21] were the first to question the possible circadian modulation of imagined actions that engaged different parts of the body, such as the upper and lower limbs. For both writing and walking tasks (8 meters), those authors reported similar rhythmic changes within a period of 24 hours for the duration of executed and simulated actions as well as for the isochrony principle. They observed that the ability to form accurate motor images is higher in the afternoon (between 14:00 to 20:00 h) than in the morning (8:00 and 11:00 h) or in the evening (23:00 h). The influence of both task constraints (duration and complexity) and circadian modulations on isochrony between overt and covert actions has been examined for simple (8 m), complex (7 m slalom + 25 kg), short (2 m) and long (40 m) walking tasks.[22] For the complex, short and long walking tasks, no influence of circadian modulation was detected. By contrast, circadian modulation influences isochrony between the executed and simulated actions for the simple walking task; participants' imagery quality was higher between 14:00 to 20:00 h as observed for writing and walking.[21] These data suggested that circadian modulation on motor imagery is not systematic but task-related, although this aspect has not always been reported. Task difficulty did not actually modify circadian modulation for arm pointing movements,[23] with higher temporal equivalence between executed and imagined arm movements in the afternoon. Overall, these studies emphasized that motor imagery quality was not constant throughout the day, although questions remain regarding the importance of task difficulty in these circadian modulations. This time-of-day effect on motor action simulation should be considered when scheduling motor imagery practice during motor learning or rehabilitation sessions. However, if task constraints prevail over that of circadian modulation in some circumstances, this means that the daily schedule of motor imagery practice may not be generalizable. The fluctuations in motor imagery quality throughout the day for elderly hospitalized persons remain an important and unresolved issue in rehabilitation science. This question is all the more important because a task that is simple for young adults may be more complicated for the elderly.

The effect of age on circadian rhythms has been highlighted in the literature on a wide range of cognitive tasks measuring memory, attentional capacities and executive functioning.[24] Many studies assessing cognitive aging have shown that performance of the elderly deteriorates throughout the day, whereas it improves for younger adults.[25,26] The general pattern that emerges is that time-of-day modulation in cognitive abilities revealed higher accuracy in the early afternoon and lower accuracy in the morning for young adults. By contrast, time-of-day accuracy in the elderly tends to be in the morning. However, a more complex picture emerges than a mere morning advantage for elderly cognitive abilities. There is some evidence that aging seems to be associated with a reduction in the amplitude of circadian modulation on cognitive abilities[27,28] and nonoptimal time-of-day.[26]

To date, no study has investigated the effects of circadian modulation on motor imagery quality in a geriatric hospitalized population engaged in a daily program of rehabilitation activities. The use of motor imagery to help reduce the impact of age-related sensorimotor impairment is justified by behavioral and neuroimaging studies.[29] Psychophysiological data revealed that motor imagery quality is relatively preserved with aging for a wide range of movements, except for constrained movements such as fast and accurate arm displacements between small targets.[30] Neuroimaging data confirmed engagement of the motor network during simulation of actions in older adults.[29] Although temporal congruence between executed and simulated actions has been shown to be equivalent in younger and older adults for unconstrained and usual movements,[31,32] the importance of circadian modulation on motor imagery efficiency for aged inpatients in rehabilitation programs remains to be examined. It may be that results reported for young adults are not applicable to older inpatients[21-23] in light of the finding that cognitive abilities in older people decline from morning to afternoon, whereas the reverse phenomenon appears true for younger people. Therefore, the aim of the present study was to examine possible changes in motor imagery quality for elderly inpatients throughout the day to effectively schedule motor imagery practice in their rehabilitation activities.

Methods

Participants

Thirty-four right-handed elderly inpatients voluntarily participated (mean age 80.2 ± 6.7 years, 16 men). They were hospitalized for diverse geriatric or neurogeriatric reasons (e.g., cerebral ischemic accident, asthenia, general state alteration, fall, chronic obstructive pulmonary disease, depression, chondrocalcinosis, knee hemarthrosis). All inpatients were able to sit without assistance, manipulate objects and walk 10 meters in less than 30 seconds without technical help or with a simple stick. Inpatients were excluded from participation if they had non-stabilized infections or clinical evaluations incompatible with the protocol (e.g., uncorrected optical problems, severe dementia, psychiatric condition). All inpatients gave informed, written consent for their participation in the study and the protocol was approved by the ethics committee of the rehabilitation center where the experiment took place.

The Edinburgh Handedness Inventory[31] was used to evaluate patients' laterality (mean .90 ± .15). The short version of the Kinesthetic and Visual Imagery Questionnaire[17] was used to ensure that all patients were able to simulate movements. The test measures the clarity of visual and kinesthetic images of movements from the first-perspective with a 5-point scale (maximum score = 25 for each modality). Patients' scores indicated good visual (18.24 ± 3.95) and kinesthetic (16.21 ± 4.57) imagery abilities. Because all patients were hospitalized, the scheduled allowed for similar diurnal activity and nocturnal rest. The experiment took place in a quiet room with a constant ambient temperature (22 ± 1°C).

Tasks and materials

Participants performed two tasks: a writing task and a walking task.[21] During the writing task, they were seated in a comfortable chair in front of a table. They were asked to write or to imagine writing the French words *simulation mentale* on a sheet of paper in a natural self-selected speed. In both cases, patients performed the task with their eyes open and the pen held above the paper. The only difference was that no writing movement was made when patients imagined writing. During the walking task, patients stood upright before walking at a natural self-selected speed along a straight path of 10 meters. For the imagined walking task, patients were allowed to sit to avoid becoming tired.

For both tasks, the duration of executed and imagined movements was recorded with an electronic stopwatch[21] (Geonaute ONstart 100; temporal resolution 1 ms). The experimenter triggered the stopwatch and stopped it when the patient indicated verbally (saying "stop") that he began and finished the executed or imagined action.

Experimental procedure

Each inpatient successively performed writing and walking 7 times a day, at times compatible with the hours of rehabilitation activities. Evaluation sessions (~20 min/session) took place every 1:15 h from 9:15 to 16:45 h (9:15, 10:30, 11:45, 13:00, 14:15, 15:30 and 16:45 h). The sessions began 10 min before and ended 10 min after the reference hours.

During each session, each patient performed 4 executed and 4 imagined trials for the writing task, and 3 executed and 3 imagined trials for the walking task. During imagined trials, they were encourage to feel themselves performing the tasks (kinesthetic imagery)

On the day before the evaluation sessions, patients performed 2 executed and 2 imagined trials for each task.

Data analysis

For each patient, we first computed the average duration of executed and imagined actions for both writing and walking in each experimental session. We examined motor imagery quality by computing the isochrony index (i.e., the absolute difference between the average duration of executed and imagined actions) for each trial. An isochrony index value close to zero indicates good imagery ability. We performed analyses of variance, for writing and walking separately, on the action duration with Practice (executed vs. imagined) and Time-of-day (9:15 to 16:45 h) as within-subjects factors. Similar analyses were carried out on the coefficients of variation (i.e., the standard deviation divided by the average duration, multiplied by 100), that represent the temporal variability of executed and imagined movements. We also performed ANOVAs on the isochrony index with the Time-of-day (9:15 to 16:45 h) as a within-subject factor. T-tests were used to examine whether the isochrony index significantly differed from zero. We checked that all variables were normally distributed (using the Kolmogorov-Smirnoff test) before performing ANOVAs. For all the ANOVAs, we carried out post-hoc comparisons using the Duncan test. Alpha was set at .05.

We also detected and quantified circadian rhythms for executed and imagined actions as well as for the isochrony index. We analyzed time series for circadian rhythmicity by the cosinor method (with a predefined period of 24 hours; see for a similar procedure[21,22]). For statistically validated rhythm ($p<.05$), we estimated the following parameters: the mesor (i.e., the rhythm adjusted mean), the acrophase (i.e., the time of the maximum level in the circadian modulation), the batyphase (i.e., the time of the lowest point) and the amplitude (i.e., half the extent of the rhythmic change).

Results

For writing (Figure 1A), the ANOVA performed on the action duration revealed only a main effect of Practice [$F(1,33)=48.01$, $p=.0001$, $\eta_p^2=0.57$] with the duration of action lower for the imagined writing (9.37 ± 4.81 sec) than for the executed writing (14.12 ± 4.33 sec). For walking (Figure 1B), the ANOVA revealed a main effect of Time-of-day [$F(6,198)=4.19$, $p=.001$, $\eta_p^2=0.11$], as well as a significant Practice x Time-of-day interaction [$F(6,198)=2.29$, $p<.04$, $\eta_p^2=0.06$]. Post-hoc comparisons revealed that the action durations were not significantly different at 9:15, 10:30, 11:45, 13:00 and 14:15 h (ps>.81) between the executed and the imagined walking, while they were significantly lower at 15:30 and 16:45 h for the imagined than for the executed walking (ps<.02).

The ANOVAs performed on the coefficients of variation revealed a significant effect of Practice for the writing task [$F(1,33)=16,55$, $p<.0001$, $\eta_p^2=0.33$] and the walking task [$F(1,33)=27,45$, $p<.0001$, $\eta_p^2=0.45$]. For both tasks, the coefficients of variation were higher for the imagined (writing: 11.56 ± 7.32; walking: 9.23 ± 7.83) than for the executed movement durations (writing: 7.69 ± 4.26; walking: 4.79 ± 2.67). No significant effect of Time-of-day (ps > .18) and no Practice x Time-of-day interaction (ps > .37) appeared for both tasks.

The ANOVAs performed on the isochrony index (Figure 1C) revealed that imagery quality significantly changed as a function of Time-of-day [$F(6,198)=2.90$, $p<.01$, $\eta_p^2=0.8$] for writing. Post-hoc comparisons showed that the isochrony indexes were significantly lower at 10:30 and 11:45 h than at the other times. For walking, no significant changes over the day appeared [$F(6,198)=0.95$, $p=.46$], although the graphic representation of the isochrony index looks similar for both tasks.

/ Insert Figure 1 approximately here /

Cosinor analyses (Figure 2) revealed that circadian rhythms were detected only in the imagined durations and the isochrony indexes for both writing and walking tasks (population mean cosinor analysis, ps<.01). Table 1 illustrates the average values of the parameters of the circadian rhythms. The batyphase values confirmed that the ability to achieve motor imagery (i.e., isochrony index) was greater in late morning than in the afternoon for both writing and walking.

/ Insert Figure 2 approximately here /

/ Insert Table 1 approximately here /

Discussion

The aim of the present experiment was to examine the influence of circadian modulations on motor imagery quality for elderly inpatients. This specific point appears important to help physiotherapists and occupational therapists to determine the best time-of-day to schedule motor imagery in rehabilitation programs. Thus, we specifically examined whether imagined and executed movement durations, as well as the isochrony index, varied throughout the day for both writing and walking tasks.

The effect-of-time of day on imagined and executed movements

Our results showed that imagined movements for elderly inpatients exhibited circadian modulations within a period of 24 hours for both writing and walking, whereas no such rhythmic changes appeared for executed movements (see cosinor analyses). The lowest values for the imagined writing and walking durations appeared late in the morning, at approximately 10:00 and 12:00 h. These results differ on two points with studies reported in the literature with healthy young adults. First, the durations of both the executed and imagined movements were modulated by the circadian pattern; second, the shorter movement durations appeared in the afternoon (between 14:00 and 20:00 h). These results, which were typical of the performance of young adults, were recorded for writing and walking,[21] as well as for pointing.[23] In these studies, movements exhibited similar rhythmic changes within a 24-hour period, whether they were imagined or executed. By contrast, the dissimilar effects of time-of-day on executed and imagined movements recorded in our experiment suggest that cognitive and sensorimotor aspects of motor behaviors are different for elderly inpatients. Indeed, the results suggest a relative independence of the cognitive (i.e., imagined actions) and sensorimotor processes (i.e., executed action) for our participants because the daily variations were observed only for the cognitive processes. The age-related dissociation between executed and imagined action has been previously reported in the literature with regard to the integration of the movement constraints.[29,31] The authors suggested that a possible explanation could be that older adults rely more on online feedback mechanisms during movement execution (mechanisms absent during motor imagery) than younger adults.

The stability of the sensorimotor processes throughout the day suggested that the time-of-day is not a factor that must be rigorously taken into account in scheduling physical exercises with geriatric patients. Consistency of motor performance over the day might suggest that sensorimotor processes are more dependent on the task constraints than on the time-of day. It might be possible that due to motor difficulties, physical activity becomes less flexible with advancing age and thus less sensitive to circadian modulations. Similar conclusions have been made for young participants[22] when the effect of circadian rhythms was not systematic and disappeared as the complexity of the motor task increased. In summary, the present experiment might suggest that, for elderly inpatients, the constraints of the motor task have a stronger effect on the sensorimotor aspects of motor behaviors than circadian modulation, whereas the cognitive processes underlying imagined actions are continuously updated throughout the day with the highest values late in the morning. Note however that the effect of the constraints of the task on circadian modulation for motor performance of elderly remains to be documented.

The effect of time-of-day on motor imagery quality

An interesting finding in the present experiment concerns the circadian modulations of motor imagery quality. The isochrony index was used to evaluate whether the motor predictions for the writing and walking tasks were accurate. Note that for isochrony, a low value indicates higher motor imagery quality (i.e., good motor predictions or internal simulations) than a high value. The isochrony index showed a clear diurnal variation for both writing and walking with batyphases at approximately 10:00 and 12:00 h (10:18 and 12:10 h for writing and walking, respectively). Compared with the literature on healthy young adults, the results of the present experiment indicate that the cognitive processes implied in motor imagery differ between young adults and elderly inpatients. We showed for the first time that, for elderly inpatients, motor imagery quality was better late in the morning. These results are concordant with studies on cognitive ageing that have shown cognitive performance deteriorates throughout the day for the elderly, [24-26] whereas it improves for young adults. The similarities between the circadian modulation for healthy elderly cognitive abilities and aged inpatients motor imagery quality may suggest that age more than diseases affects the circadian rhythms of motor imagery reported in the present experiment. This specific point requires that other studies be performed in the future.

From a practical perspective, the results of the present experiment suggest that when people are engaged in a daily program of rehabilitation activities, the practitioner must propose a motor imagery practice late in the morning for elderly patients, whereas the afternoon is a more appropriate period for young adults. However, in the present experiment, the high average values of the isochrony indexes for writing (5.27 sec) and walking (3.71 sec, Figure 1C) may suggest that motor images are not very accurate in elderly inpatients. The temporal correspondence discrepancy between executed and imagined movements in elderly has been previously reported, especially for actions with high spatiotemporal constraints,[29,32-35] which indicate impairment at the level of action planning that increases with advancing age. However, the action-planning deficit in the elderly is strongly related to task requirements,[36] and there are no age-related alterations in motor imagery for the most familiar actions. This finding may explain why, in our experiment, the temporal discrepancy between executed and imagined action (Figures 1A and 1B), as well as the isochrony indexes (Figure 1C), had more influence on writing than on walking. It may be possible that, for elderly inpatients, the necessity to preserve their autonomy makes walking an important daily activity (and thus a familiar activity), which is not especially the case for writing.

Study limitations

The high values of the isochrony indexes in the present experiment lead to the question of the applicability of motor imagery for elderly inpatients. Although there are few studies on this issue, motor imagery practice was recently found to benefit elderly hemiparesis patients in sit to stand and reaching to grasp[37] and walking;[38] that is, for tasks in everyday life.

To our knowledge, no study has examined the benefit of motor imagery practice on less familiar tasks for elderly patients. We believe that the present study offers information for clinical guidelines, especially on the best time-of-day to schedule motor imagery. However, other experiments should be conducted in the future to quantify the gains due to motor imagery practice in rehabilitation activities with elderly inpatients as a function of their imagery quality and the characteristics of the task. It may be possible that many factors can modulate the improvement of performance following motor imagery practice for aged hospitalized patients. These factors should be precisely identified to allow therapists to successfully integrate motor imagery in their rehabilitation sessions.

Conclusion

The influence of circadian modulations on motor imagery quality is important to know help physiotherapists and occupational therapists to determine the best time-of-day to schedule motor imagery in rehabilitation programs. The present experiment shows that for elderly inpatients, motor imagery was better late in the morning. This finding suggests that when elderly inpatients are engaged in a daily program of rehabilitation activities, the practitioner must propose a motor imagery practice at approximately 10:00 and 12:00 h rather than in the afternoon.

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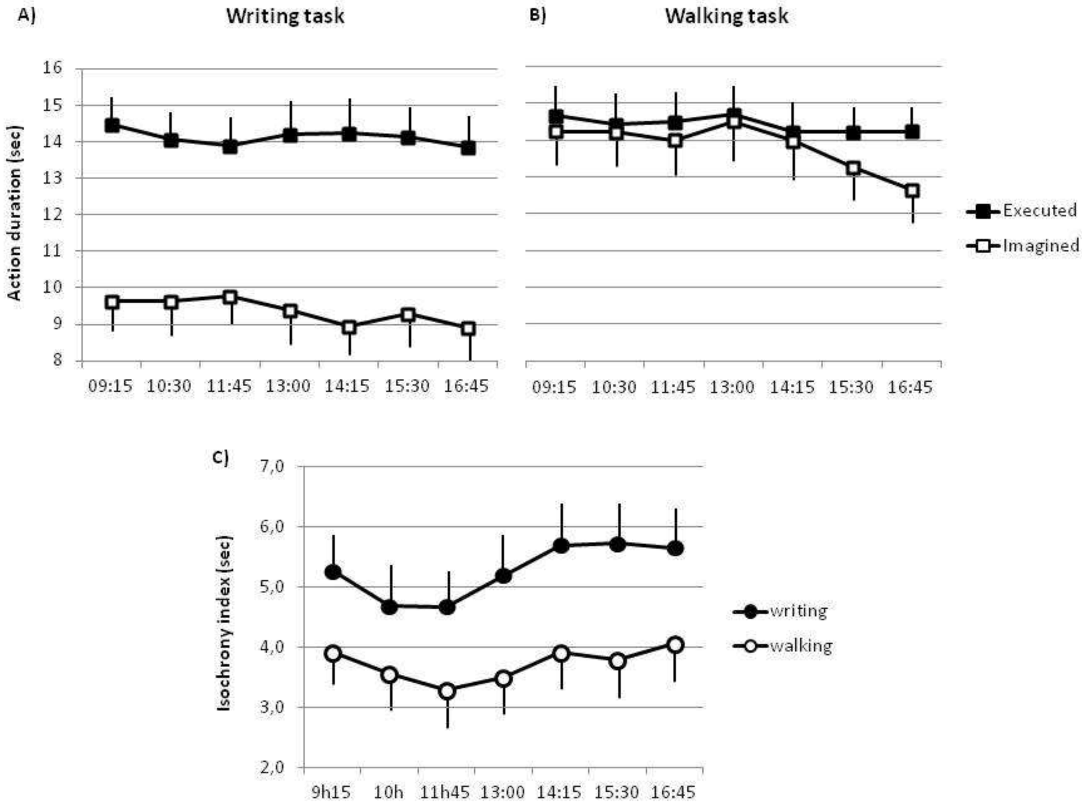
Figure captions

Figure 1. Action duration (sec) for writing **(A)** and walking **(B)** as a function of Time-of-day and Practice (executed vs. imagined). Isochrony index (sec) for writing and walking **(C)** as a function of Time-of-day and Practice. Error bars indicated the standard error of the mean.

Figure 2. Average and standard error of the mean for imagined duration (sec) and isochrony index (sec) for writing (left panels) and walking (right panels) as a function of Time-of-day. The best-fitted cosine curves are depicted. The dashed line shows the average value of the Mesor for each variable.

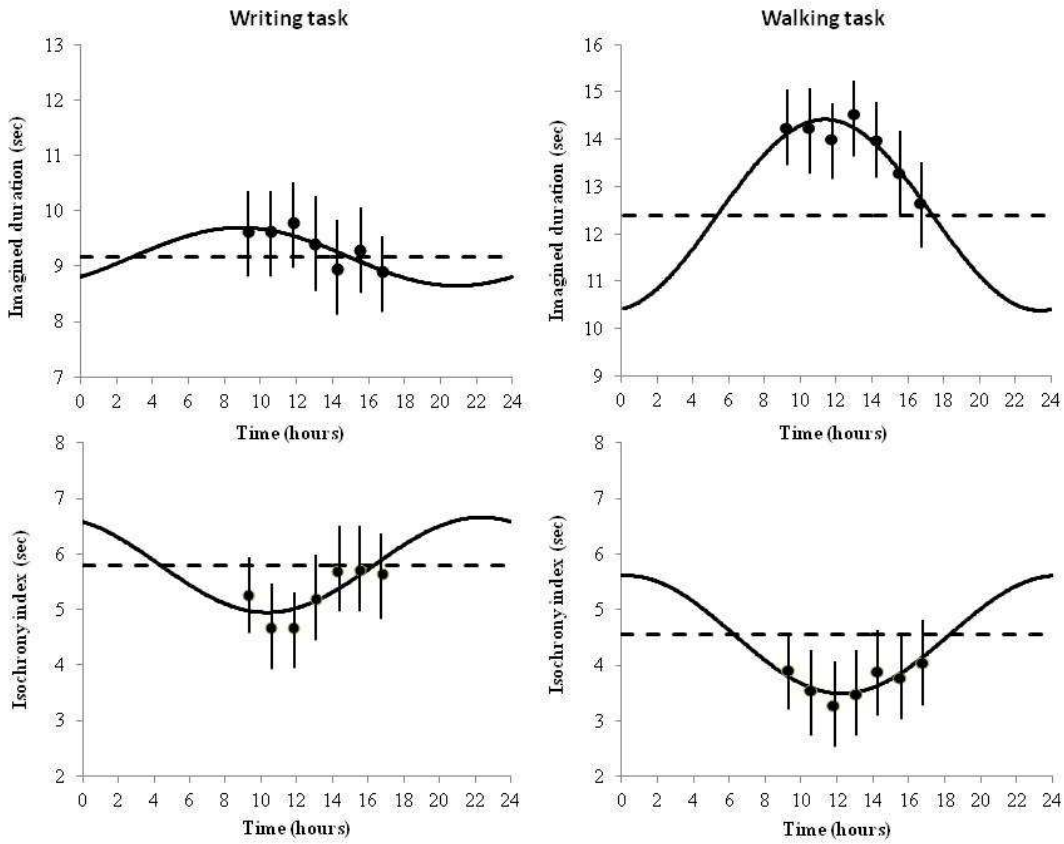
Table 1. Characteristics of the circadian rhythms for the writing and the walking tasks

		Mesor	Amplitude	Batyphase
Writing task	Imagined duration	9.17	1.05	20:43
	Isochony index	5.80	1.71	10:18
Walking task	Imagined duration	12.4	4.04	23:24
	Isochony index	4.55	2.12	12:10



A)
Writing task
B)
Walking task
Action duration (sec)
16
15
14
13
12
11
10
9
8
09:15
10:30
11:45
13:00
14:15
15:30
16:45
Executed
Imagined
C)
Isochrony index (sec)
7,0
6,0
5,0
4,0
3,0
2,0
9h15
10h
11h45
13:00
14:15
15:30
16:45
writing
walking

Figure 1



Writing task
Walking task
Imagined duration (sec)
Isochrony index (sec)
Time (hours)

Figure 2