Fatigability is closely associated with discoordination between heart rate variability and physical acceleration during free-moving days in younger women

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Abstract

Background

Fatigability is related to several diseases and the autonomic nervous system. We investigated whether fatigability is associated with the coordination between the physical acceleration (PA) and heart rate variability (HRV) in women.

Method

Overall, 95 adult women were divided into younger group ($n = 50$; age: 22–59 years) and older group ($n = 45$; age: ≥ 60 years). HRV and PA data were simultaneously obtained every minute for 24 h. We defined %lag0 as the percent ratio of lag = 0 min between HRV and PA in 1 h. Cornell Medical Index was used to determine the degrees of physical and psychological symptoms.

Results

In the younger group in the hour before sleep, the participants with high fatigability scores had significantly lower ($p < 0.05$) %lag0 than did those with low fatigability %lag0. Additionally, those with higher fatigability combined with exhaustion in the morning had significantly lower %lag0 than did those without exhaustion in the hour before sleep but not in the hour after waking up ($p < 0.05$).

Discussion

These results suggest that the coordination between HRV and PA in younger women was closely associated with their fatigability in the hour before sleep. Additionally, exhaustion in the morning may be related to the discoordination of HRV and PA the previous night.

Background

Fatigue is a one of the major symptoms in general conditions irrespective of health or illness. A large survey reported that half of the general population suffers from fatigue [1]. There are some differences between fatigue and fatigability; therefore, assessment of fatigability can be used to better characterize fatigue [2]. Fatigability has been defined as the degree of fatigue experienced during the performance of a defined activity, which normalized fatigue to activity level [3]. Understanding fatigability is important in evaluating the impact of fatigue on physical activities and vice versa [4]. Furthermore, it has been reported that the fatigue experienced in the morning and may be distinct from that in the evening; however, both are closely related to each other [5].

Cornell Medical Index (CMI)—a questionnaire devised for collecting a large amount of pertinent medical and psychiatric data with minimum expenditure of resources—includes a section on fatigability [6]. We used this questionnaire in this study because it has been widely used in clinical practice as a screening procedure to evaluate neurotic tendencies [7]. Furthermore, we employed the term “fatigability” based on its usage in CMI.

The fatigability in older people is different from that in younger ones [8]. There are age-related differences in the neurovascular and neuromuscular systems between the two; therefore, older people exhibit different rates of fatigability than young adults during a fatigable task. However, the mechanism underlying the age-related differences in fatigability is not fully understood [9].

Heart rate variability (HRV) is a non-invasive tool to assess the variations in beat-to-beat interval. It is used to assess the cardiac autonomic functions and is related to the outcomes following cardiac events and stress [10, 11]. Most human studies on the HRV spectrum for the low-frequency (LF: 0.04–0.15 Hz) and high-frequency (HF: 0.15–0.40 Hz) spectral power bands [10]. A study has previously demonstrated that patients with chronic fatigue syndrome had significantly lower average daily physical acceleration (PA) [12].

The coordination is defined as the time lag between PA and HRV. Based on cross-correlation analysis, we previously reported that the lag in older participants was significantly higher than that in the younger participants [13].

Habitual physical activity and HRV have been reported to differ significantly between men and women [14, 15]. Broadly speaking, young women are less fatigable than young men during isometric fatiguing contractions [16]; therefore, fatigability depends on the sex of the individual as well. The aim of the present study was to investigate if there is a correlation of age and fatigability with coordination in women.

Methods

Participants

Overall, 106 adult women (age: 20–85 years) volunteered to participate in this study. Based on medical interviews, physical examinations, laboratory blood investigations, and electrocardiogram (ECG), we excluded five participants who had consumed alcohol on the day of the experiment, six participants with severe arrhythmias, two participants who were on beta-blockers, and three participants with excessive electrical noise in the devices described below (Fig. 1). Arrhythmias were identified using 12-lead ECG and ECG complexes derived using Lorenz plots [17]. Finally, we examined 95 participants with the following comorbidities. However, these comorbidities were mild and none of the subjects had restricted movements. The younger group included four students, 14 housewives, eight full-time employees, and 24 part-time employees. The older group included 13 part-time workers and 32 housewives.

Protocols

The participants completed the questionnaire before or on the day of the assessments. They arrived at the laboratory at approximately 13:00 and underwent venous blood sampling and ECG. They wore a portable monitor (Active Tracer AC301; GMS Inc., Tokyo, Japan) that recorded PA and R-R intervals over 24 h. During monitoring, the participants were instructed to continue their usual lives and avoid bathing. After the completion of the 24-h monitoring, they returned to the laboratory. The experimental protocols were described in detail previously [13, 18]

Questionnaires

We used the Japanese version of CMI (J-CMI) (Sankyobo Co. LTD., Kyoto, Japan) which was created by Kanehisa and Fukamachi (1972) to assess the physical and psychological symptoms [19, 20]. J-CMI for women comprises 213 questions in 18 sections. Fatigability includes the following seven questions: “Do you often get spells of complete exhaustion or fatigue?”; “Does working tire you out completely?”; “Do you usually get up tired and exhausted in the morning?”; “Does every little effort wear you out?”; “Are you constantly too tired and exhausted even to eat?”; “Do you suffer from severe nervous exhaustion?”; and “Does nervous exhaustion run in your family?”. Each question is answered as “yes” or “no” and is scored as one or zero. A yes response indicated that the individual has currently or previously experienced the symptoms [6].

Physical Activity

The body of the Active Tracer (GMS Inc.) equipped with a triaxial accelerometer (72 g) [21, 22] was positioned on the frontal midline of the waist above the navel to avoid free movement of the device. The resolution of acceleration was 2 mG, and the sensitivity ranged between 0 and 4.0 G. The absolute values of the resultant vector, which were calculated from the signals of triaxial acceleration, were averaged every 1 min.

Analysis

Spectral analysis of HRV was performed at 1-min intervals using maximal entropy combined with the least square method (MemCalc System; Suwa Trust Co., Ltd., Tokyo, Japan) and, subsequently, separated into the HF and LF ranges for power analysis [10]. These indices were defined as LFnu = LF/(LF + HF) and HFnu = HF/(LF + HF). They are regarded as the markers of the sympathetic and parasympathetic nervous systems, respectively [23]. We estimated the times at which the participants fell asleep and woke up based on the changes in the body positions evaluated by the monitor.

Definition of %Lag0

Lag was determined as the time difference indicated by the maximum correlation coefficient obtained from the analysis of the cross-correlation between HRV and PA. Cross-correlation coefficients were calculated for 10-min moving time windows over consecutive 60-min periods. We defined impairments of coordination between HRV and PA as lag time of 1 min or longer. The lag analysis has been discussed in detail in our previous study [13]. Subsequently, we defined %Lag0 as the percentage of lag = 0 min in 1 h and it is an index of coordination between HRV and PA. Low levels of %Lag0 indicate discoordination between PA and HRV.

Statistics analysis

Data are expressed as mean ± standard error of the mean. Statistical analyses were performed using unpaired *t*-test and Microsoft Excel. $p < 0.05$ was considered statistically significant.

Ethics

This study was approved by the Ethics Committee at the National Cerebral and Cardiovascular Research Center, Chubu University and Kyoto University. All participants provided written informed consents prior to participation in this study.

Results

The participants were divided into the following four groups: group I: younger with low fatigability (age < 60 years and fatigability score < 3; n = 39); group II: younger with high fatigability (age < 60 years and fatigability score ≥ 3; n = 11); group III: older with low fatigability (age ≥ 60 years and fatigability score < 3; n = 31); and older with high fatigability (age ≥ 60 years and fatigability score ≥ 3; n = 14). There were no significant differences in the age, body mass index (BMI), sleeping hours and PA between groups I and II. In contrast, the older participants with high fatigability had significantly longer sleep duration and higher PA in the evening compared with those with low fatigability (Table 1).

Table 1
Comparisons of the basic characteristics of age, BMI, sleeping hours, PA, HFnu, and LF/HF between fatigability scores.

group		**I**	**II**	**III**	**IV**
age (years)		< 60	< 60	≥ 60	≥ 60
fatigability		< 3	≥ 3	< 3	≥ 3
n		39	11	31	14
Age		41.9 ± 1.9	44.9 ± 3.8	70.4 ± 1.0	70.7 ± 1.6
BMI		21.9 ± 0.5	22.4 ± 0.7	22.3 ± 0.5	23.9 ± 1.0
sleeping hours(h)		6.9 ± 0.2	6.6 ± 0.6	7.2 ± 0.2	8.0 ± 0.3*
Frequency of nocturnal awakening		0.4 ± 0.1	0.8 ± 0.3	1.0 ± 0.1	1.2 ± 0.3
PA	evening	37.9 ± 2.2	42.9 ± 4.7	43.8 ± 2.0	33.2 ± 3.4*
	morning	51.3 ± 3.1	46.3 ± 4.4	54.8 ± 4.0	42.7 ± 4.7

* $p < 0.05$ III *vs.* IV

BMI, body mass index; PA, physical acceleration; HF, high frequency; LF, low frequency; HFnu = HF/(LF + HF).

Table 2
%Lag0 before sleep and after waking up in response to the questionnaire items.

Before sleep	**younger**		**Older**	
Questionnaires	No	Yes	No	Yes
Q1: Do you often get spells of complete exhaustion or fatigue?	62.8 ± 6.8	48.3 ± 10.9	31.6 ± 7.2	29.4 ± 7.2
	54.9 ± 6.4	47.0 ± 10.4	23.8 ± 6.7	27.6 ± 6.5
Q2: Does working tire you out completely?	66.9 ± 6.6	39.8 ± 10.2*	33.5 ± 7.6	27.1 ± 6.6
	55.3 ± 6.5	46.1 ± 6.5	27.0 ± 6.8	19.1 ± 5.8
Q3: Do you usually get up tired and exhausted in the morning?	66.3 ± 6.0	21.5 ± 10.7**	29.2 ± 5.6	36.7 ± 12.4
	60.3 ± 5.7	16.3 ± 8.1**	23.8 ± 5.5	27.6 ± 9.4
Q4: Does every little effort wear you out?	60.7 ± 6.3	48.3 ± 14.7	34.1 ± 9.5	22.2 ± 7.0
	55.5 ± 6.0	39.7 ± 12.9	24.9 ± 8.4	23.6 ± 8.6
After wake-up	**younger**		**Older**	
Questionnaires	No	Yes	No	Yes
Q1: Do you often get spells of complete exhaustion or fatigue?	44.5 ± 5.5	40.7 ± 10.2	14.4 ± 4.2	33.9 ± 7.7
	31.6 ± 5.2	29.9 ± 8.7	9.0 ± 3.6	19.1 ± 5.8
Q2: Does working tire you out completely?	44.6 ± 5.8	40.5 ± 9.4	13.7 ± 3.9	24.2 ± 7.2
	30.3 ± 5.4	32.5 ± 8.3	9.1 ± 3.9	13.5 ± 5.0
Q3: Do you usually get up tired and exhausted in the morning?	45.8 ± 5.3	31.9 ± 13.1	14.4 ± 3.6	33.9 ± 12.6
	31.1 ± 4.9	30.9 ± 10.5	9.0 ± 3.9	19.0 ± 9.4

*: $p < 0.05$, questionnaire no *vs.* yes
**: $p < 0.01$, questionnaire no *vs.* yes

Before sleep	younger		Older	
Q4: Does every little effort wear you out?	45.7 ± 5.3	33.7 ± 12.9	25.9 ± 6.7	16.8 ± 7.3
	31.0 ± 4.9	31.3 ± 11.0	13.6 ± 6.9	10.0 ± 4.7
*: $p < 0.05$, questionnaire no *vs.* yes				
**: $p < 0.01$, questionnaire no *vs.* yes				

Representative data of a participant with low fatigability and lag = 0 of PA and LF/HF before night sleep is presented in Fig. 2. Similarly, the representative data of a participant with high fatigability and lag = 3 min of PA and LF/HF before night sleep is presented in Fig. 3, which indicates that PA preceded LF/HF.

In the hour before sleeping at night (panel 1 in Fig. 4), younger participants with high fatigability had significantly lower %Lag0 between HFnu or LF/HF and PA than those with low fatigability (left panel I in Fig. 4). However, in the older groups, there were no significant differences in %lag0 (right panel I in Fig. 4). In the hour after night sleep, there were no significant differences in %lag0 between participants with low fatigability and those with high fatigability, both, in the younger and older groups (panel II in Fig. 4).

Of the 50 younger participants, the numbers of those who answered “yes” for the aforementioned seven questions were 16, 16, 9, 10, 1, 2 and 4, respectively. Of the 45 older participants, 9, 20, 9, 13, 0, 1 and 3, respectively, answered yes to the same questions. In the hour before sleep, those in the younger group who answered “yes” to question no. 2 had significantly lower %lag0 between HFnu and PA than those who answered “no”. Additionally, those who answered “yes” for question no. 3 had significantly lower %lag0 between HFnu or LF/HF and PA than those who answered “no”. Statistical analyses were not performed for the relationships between %lag0 and the answers to questions 5, 6, or 7 because the numbers were too small numbers to be analysed.

Discussion

The major finding of this study was that the participants in the younger group with high fatigability scores had significantly lower %lag0 compared with those with low fatigability in the hour before sleep; however, the difference was not significant in the hour after waking up. Additionally, participants in the younger group with higher fatigability and exhaustion in the morning had significantly lower %lag0 than those without exhaustion in the hour before sleep but not in the hour after wake-up.

In younger participants, no significant differences were observed in the basic characteristics between the high and low fatigability groups. In the older group, however, the high fatigability group had significantly longer sleeping hours and lower PA in the evening than the low fatigability group. The sleeping hours at night also involved nocturnal awaking. A previous study reported that improved sleep may result in low fatigability in older people [24]. Additionally, an experimental study has demonstrated that exercise has a positive effect on sleep in older adults with sleep compliments [25]. Therefore, we believe that low PA before sleep is linked with low sleep quality and fatigability.

In the younger group, %lag0 one hour before sleep between HRV (both HFnu and LF/HF) and PA was significantly higher in the low fatigability group than that in the high fatigability group (Fig. 1). There were no such significant differences in the older group. It has been reported that fatigue stems not only from training overload or daily activities with inadequate rest but also from various inputs, such as psychological stress [26]. Therefore, daily PA may be related to fatigability and, thus, affect HRV. Therefore, fatigability may be one of the factors that affects the coordination between HRV and PA in younger people.

Both, in younger and older participants, there were no significant differences in %lag0 one hour before sleep between HRV (both HFnu and LF/HF) and PA between the low and high fatigability groups. In the hour after waking up, the participants generally performed a higher number of daily activities than they did in the hour before sleep. Therefore, we believe that the hour before night sleep is the most appropriate time period to assess the relationship of fatigability and the coordination between HRV and PA. We also believe that %lag0 in the hour before sleep and that in the hour after waking up had different clinical meanings since %lag0 of these two time periods had no significant correlation (Appendix 1).

The participants who answered “yes” to the question “ Do you usually get up tired and exhausted in the morning?” had significantly lower %lag0 between HFnu and LF/HF and PA in the hour before sleep than those who answered “no”. This may indicate that discoordination between the autonomic nervous system and PA before sleep is related to fatigability after waking up. A previous report demonstrated that morning and evening fatigue may be distinct but related symptoms [27]. Our findings could help distinguish the differences; we believe that fatigue in the morning is derived from the previous night. In this study, those who were employees had significantly higher fatigability than housewives, which may account for this difference. Further studies are required to elaborate on this topic.

In this study, we focused on evaluating the relationship between fatigability and HRV more clearly. A previous study demonstrated that mental fatigability and altered HRV are both related to selective regions of the prefrontal cortex, which build a functional circuit [28]. In this study, younger women had significant differences in %lag0 of PA and HRV between the high and low fatigability groups in the hour before night sleep, although no significant differences were observed in HFnu or LF/HF before, during, or after night sleep. Therefore, we believe that fatigability may affect selective regions of the brain that, in turn, affect the coordination between HRV and PA rather than the autonomic nervous system. This index could be useful for public health or sports science in formulating measures to avoid fatigability.

Limitations

The analytical method employed in the present study to evaluate fatigability and the coordination between the autonomic nervous system and physical activity has several limitations. This study did not include controls with matched comorbidities or physical conditions. All participants had no or mild diseases, which may have affected HRV or daily activity. We believe that various metabolic and/or neuromuscular diseases could be involved in the discoordination.

Conclusions

The coordination between HRV and PA was diminished due to fatigability in younger participants in the hour before sleep. Additionally, %lag0 can be estimated using a non-invasive and simple method.

Abbreviations

HRV	heart rate variability
HF	high frequency
LF	low frequency
PA	physical acceleration
CMI	Cornell Medical Index
J-CMI	Japanese version of CMI
%Lag0	percent ratio of the lag = 0 min in 1 h
ECG	electrocardiogram

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee at the National Cerebral and Cardiovascular Research Center (M18-19-2, M26-158), Chubu University (280031) and Kyoto University (R1758). All participants provided written informed consents prior to participation in this study.

Consent for publication

All participants provided written and explicit consent for their anonymised data to be used in publications.

Availability of data and materials

The data generated during the current study will be available from the corresponding author on reasonable request and in accordance with consent and ethical approval.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

KT performed all parts of the method and wrote all of the manuscript. A Shimouchi performed experimental plan and methodological procedures, rewrote all parts of the manuscript. NJ performed several parts of the experiment and gave advices for presentation. A Seiyama gave an idea of analysis and rewrote the original manuscript. All authors have read and approved the manuscript

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Figures

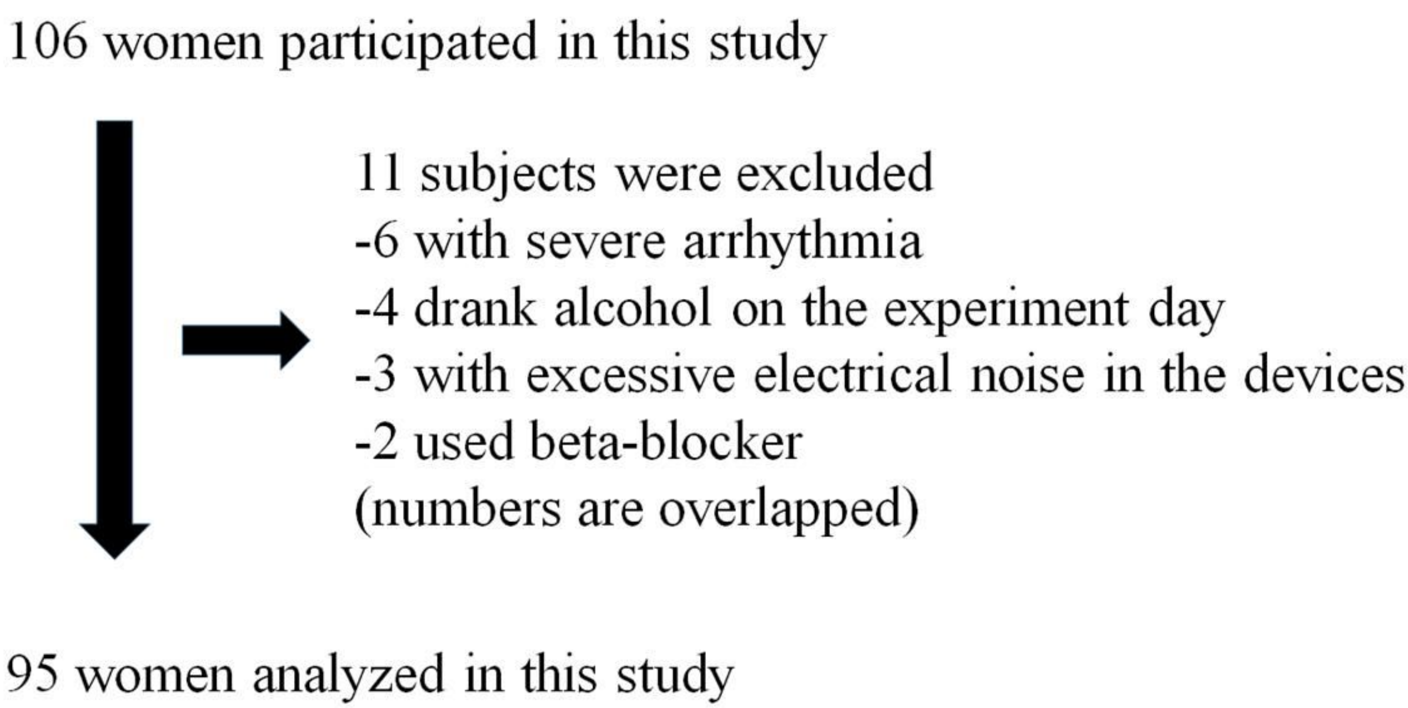

Figure 1

The study population for the evaluation of coordination between heart rate variability (HRV) and physical acceleration (PA).

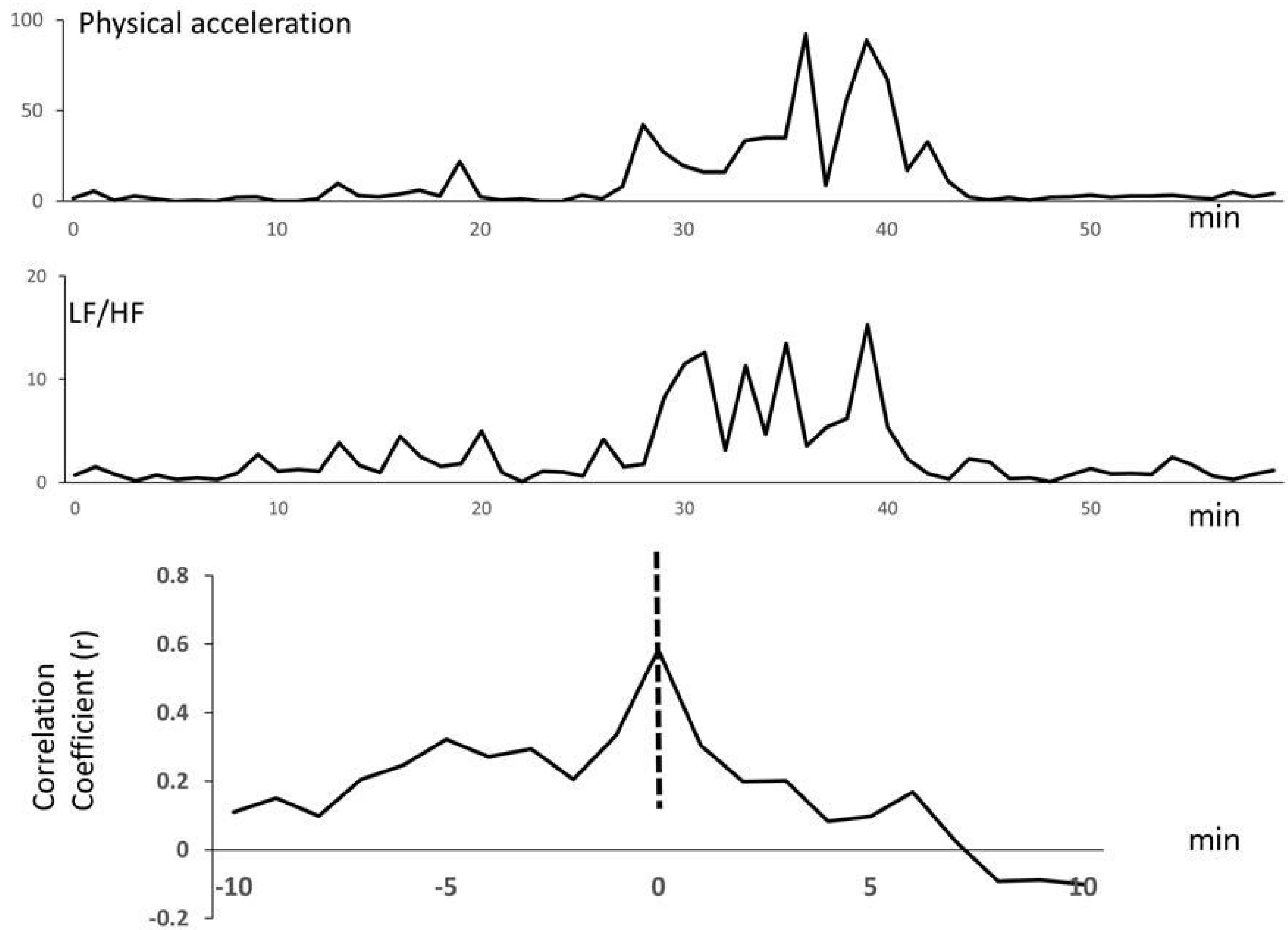

Figure 2

Lag = 0 in PA and LF/HF. PA, physical acceleration; LF/HF, low/high frequency

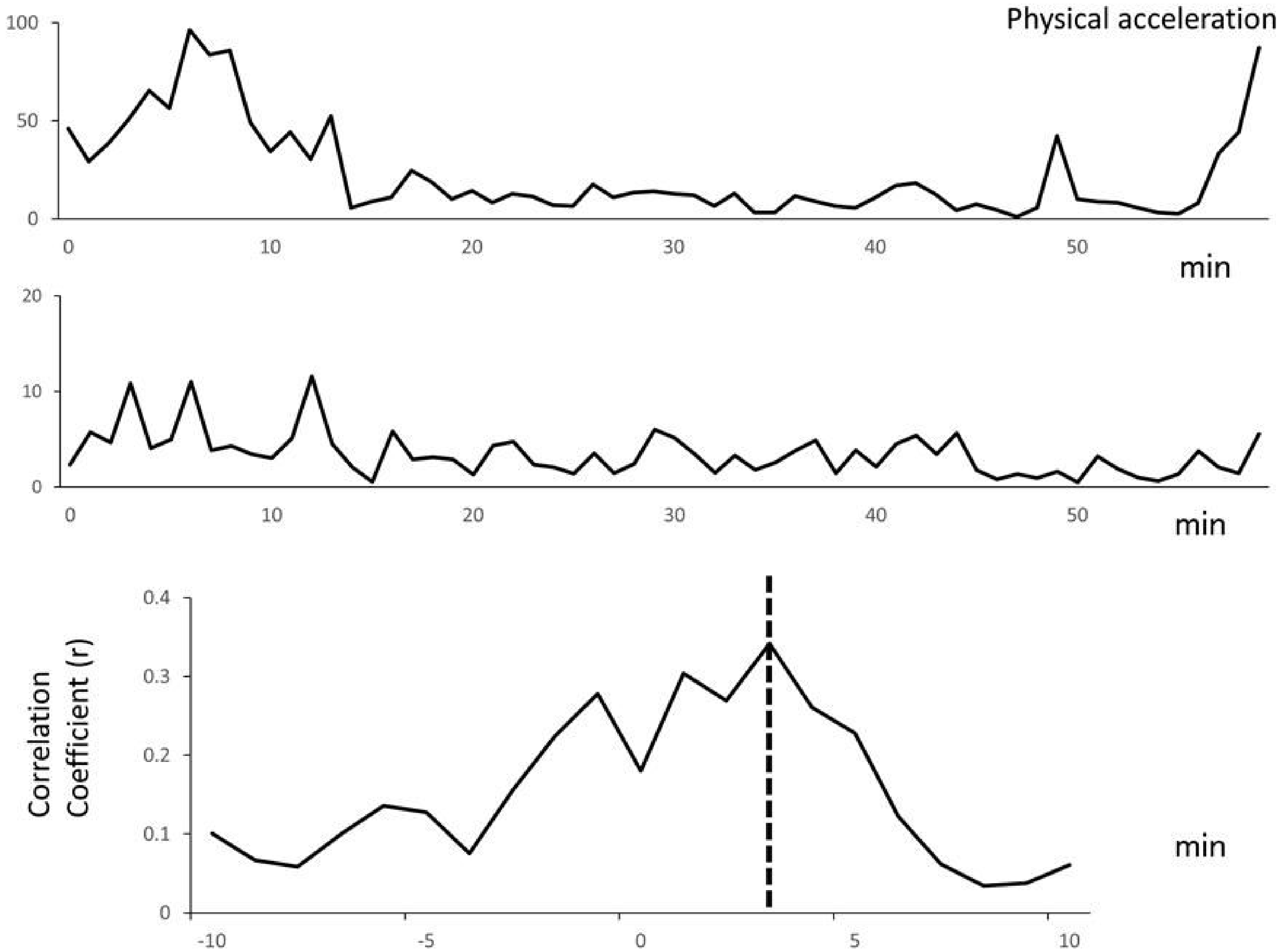

Figure 3

Lag = 2 min of PA and LF/HF before night sleep PA, physical acceleration; LF/HF, low/high frequency

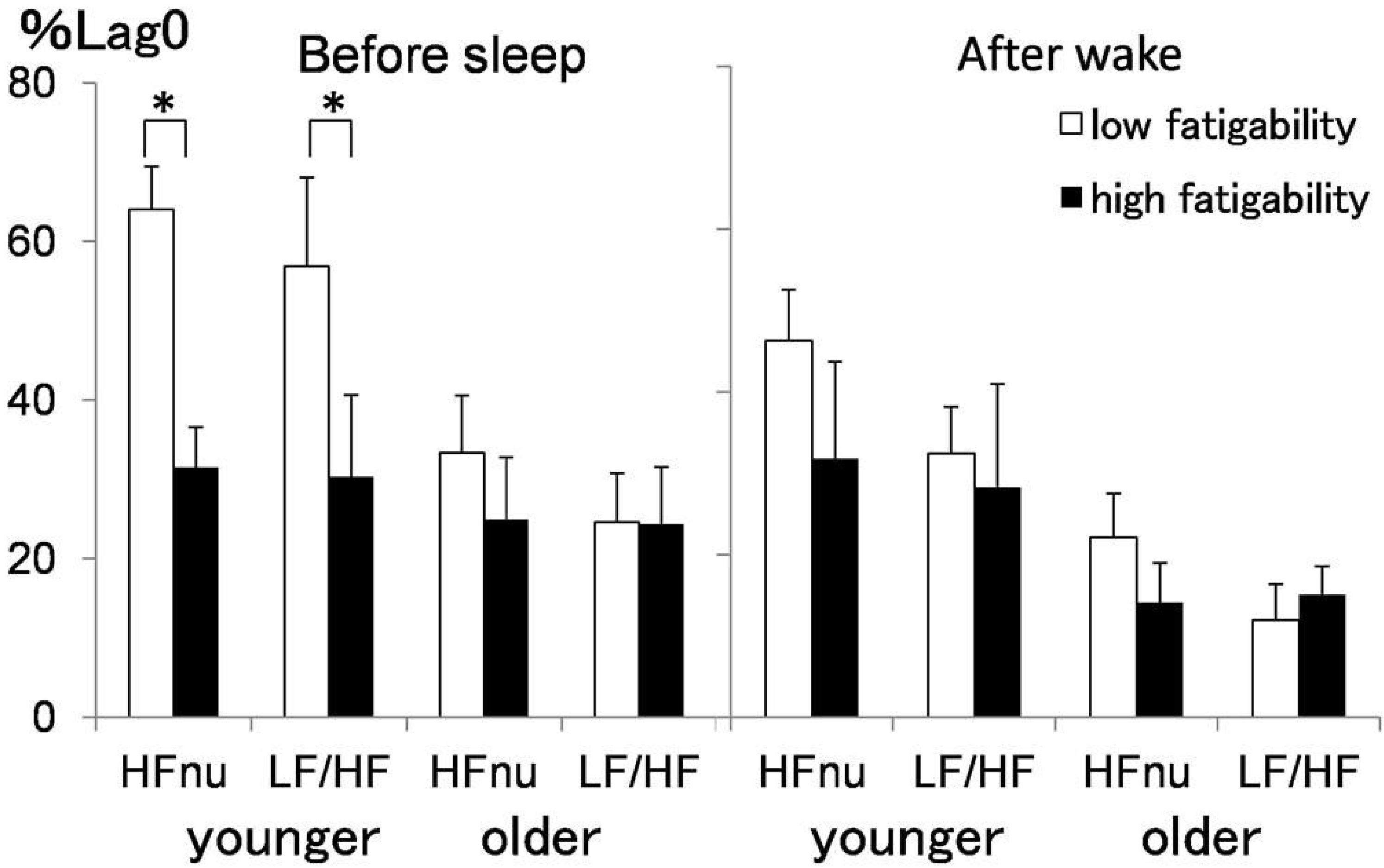

Figure 4

The relationship between %lag0 and fatigability during 1 h before and after night sleep in the younger and older groups. * p < 0.05 low fatigability vs. high fatigability

Supplementary Files

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- QuestionnaireinEnglishCMI.pdf
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