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# Early Detection of Fatigue based on Heart Rate Dynamics in Sedentary Computer Work in Young and Old Adults


Ramtin Zargari Marandi[1,2], Pascal Madeleine[1], Nicolas Vuillerme[1,2,3], Øyvind Omland[4], Afshin Samani[1]

[1]Department of Health Science and Technology, Sport Sciences, Aalborg University, 9220 Aalborg, Denmark
[2]University Grenoble Alpes, 38400 Grenoble, France
[3]Institut Universitaire de France, 75231 Paris, France
[4]Aalborg University Hospital, Clinic of Occupational Medicine, Danish Ramazzini Center, 9000 Aalborg, Denmark

afsamani@hst.aau.dk



**Abstract.** The growing number of elderly workers calls for finding objective measures for monitoring mental state to avoid risk factors of fatigue. Heart rate is a physiological index which nowadays can accurately and reliably be measured with affordable and unobtrusive gadgets e.g. wristbands. In this study, 36 participants (17 old and 19 young adults) were recruited to perform a prolonged 40-min mentally demanding task including 240 cycles while their heart rate was measured. Each cycle began by memorizing a random pattern of connected points displayed on a computer screen following by replicating the pattern while only the points constructing the pattern were shown. The replication was performed by clicking using a computer mouse on the points to redraw the connecting lines in a sequential manner. The task performance in each cycle was calculated based on the accuracy and speed in responding. After each 20 cycles, i.e. one segment, participant rated their perceived mental fatigue on Karolinska Sleepiness Likert scale (KSS) while the task execution was paused for 5s. The mean and range of heart rate, HRM and HRR respectively, in each cycle were calculated and together with the task performance were averaged across each segment for each participant. Repeated measures analysis of variance was employed to assess the effect of time-on-task (TOT), i.e. 12 segments, on the aforementioned cardiac (HRM and HRR), behavioral (task performance) and subjective (KSS) measures considering the effect of age as the between participant factor. The statistical analysis revealed that the range of heart rate followed an increasing trend both in the young and elderly group with a significant main effect of TOT, $p<0.001$. The HRM was exhibited a tendency to increase as a function of TOT both in the young and elderly group, $p=0.054$. The performance was also significantly affected by the TOT in both the young and elderly groups, $p<0.001$, with an increasing trend in the elderly group and a fluctuating trend in the young group. The KSS increased in both groups as the golden standard of increasing mental fatigue with the TOT, $p<0.001$. No interaction between TOT segments and age groups were found in any of the measures except in the performance with the higher ones for the young group as expected. The results provide useful information on the feasibility of using heart rate as an index to monitor the transition into mental fatigue state.

**Keywords:** Mental Fatigue, Aging, Heart Rate Variability.

# 1 Introduction

Aging workforce prioritize mental health into consideration of futuristic workplace design, specifically for mentally demanding tasks such as computer work. Such a futuristic design would have the flexibility to adapt based on user's health condition. This requires acquiring relevant biological data in an unobtrusive manner. One of the accessible choices is heart rate monitoring which is easily feasible using wearable heart rate sensors [1], [2].

One important problem during sustained computer work is the development of mental fatigue. Some studies affirm the usability of heart rate in the detection of mental fatigue [3]–[5]. Since heart rate is regulated by the autonomic nervous system [6], this association is seemingly plausible. However further studies have been suggested to explore the association between heart rate and fatigue development [4], especially amongst individuals from different age groups.

In this study, we aimed to analyze the changes of heart rate characteristics during a prolonged computer work both in young and old adults to see whether we can use them as biomarkers for the detection of mental fatigue development. We have employed a fitness tracker to record heart rate while individuals performed the computer work with mental demands. We statistically analyzed the association between the heart rate features and the time-on-task (TOT).

# 2 Materials and Methods

## 2.1 Participants

Twenty participants as a young group, nine females, aged 23 (*SD* 3) years, and 18 participants, 11 females, aged 58 (*SD* 7) as an elderly group voluntarily participated in this study. They were right-handed, had normal or corrected to normal vision, and reported no background of mental or psychological disorders, and no history of chronic fatigue. The participants were asked to obstinate alcohol for 24 h, and caffeine, smoking and drugs for 12 h prior to experimental days. Two participants (one from each group) were dropped out for missing data. The study was approved by The North Denmark Region Committee on Health Research Ethics, project number N-20160023, and conducted in accordance with the Declaration of Helsinki.

## 2.2 Experimental procedure

A task (WAME 1.0, [9]) was developed in a graphical user interface (MATLAB R2015b) based on standard models of computer work [10], [11]. The participants were sitting behind a desk to perform the task on a computer screen using a computer mouse. The task has been described in our previous work [11]. Briefly, the task was displayed to the participants on a 19 inch LCD monitor (1280×1024 pixels). The participants underwent 40-min of the task. The participants instructed to perform 5-min episodes of task to get familiar with the task. The task consisted of 240 cycles. After each 20 cycles, a segment, participants indicated their mental fatigue level on Karolinska Sleepiness Scale (KSS) [12] ranging from 1 up to 9 respectively corresponding to "Very alert" and "Very sleepy, fighting sleep" in five seconds. Each cycle began with memorization of a pattern of connected points in different shapes. It was followed by fixating on a single point while the pattern was not displayed. Afterwards, the points without connecting lines appeared and the participant had a limited time to click on the points in a specific order to replicate the recently memorized pattern. An extra point (distracting point) was also shown during the replication period which must not have been clicked. A new cycle with a new pattern appeared after the offset of each cycle with no pause in between. The patterns were generated randomly subject to some constraints. No loop or crossings were allowed for the lines connecting the points. The length of the lines and the angles made in the connection of two lines were limited to ensure central location of the connected pattern in the center of computer screen. The experiments were performed in the same time of the day (10-12 a.m. or 1-3 p.m.) to lower the possible effects of variation in circadian rhythms. The first two sections of each cycle took 2.34 seconds, and the third section of a cycle took 5.06 seconds.

### 2.3 Measurements

The heart rate was recorded during each task episode using A300 fitness tracker (Polar Electro Oy, Finland). This device provides instantaneous heart rate in one second intervals. The asserted accuracy of the heart rate measurement is about ±1% or 1 bpm in stable conditions which may also apply in our experimental setting with sedentary computer work. The validity and usability of this device have been approved in an independent study [13]. From the heart rate data, we extracted the mean and range of heart rate (respectively indicated by HRM and HRR) during each cycle and averaged them across cycles for each segment.

We also measured the performance of doing the task based on the clicking accuracy and speed. As described previously [9], the accuracy was computed based on how complete the patterns were replicated considering all clicks. The speed referred to how fast the pattern replication was drawn by the participants. The performance measure was monotonically related to how well the participants performed the task.

In addition, we acquired the subjective ratings of perceived mental fatigue on a Likert scale from zero (no fatigue at all) to 10 (extremely fatigued) before and after the task.

### 2.4 Statistics

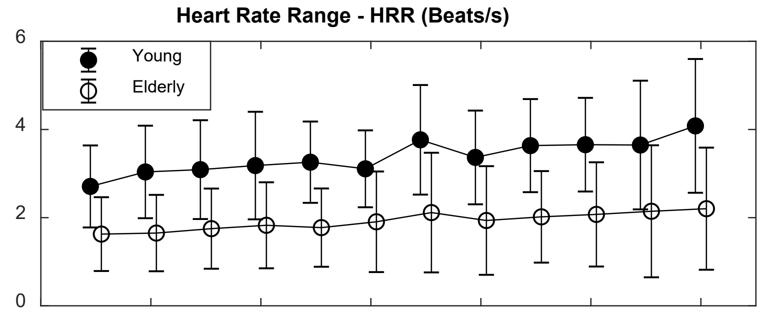
Repeated-measures analysis of variance used to examine the effects of change in segments (1-12) on cardiac features (HRM and HRR), performance, and KSS. The mental fatigue scores acquired before (baseline) and after the task was compared using paired t-test. If the assumption of sphericity was not met, a Greenhouse-Geisser correction was applied. Bonferroni adjustment was used for pairwise comparison across the mental load levels.

## 3 Results

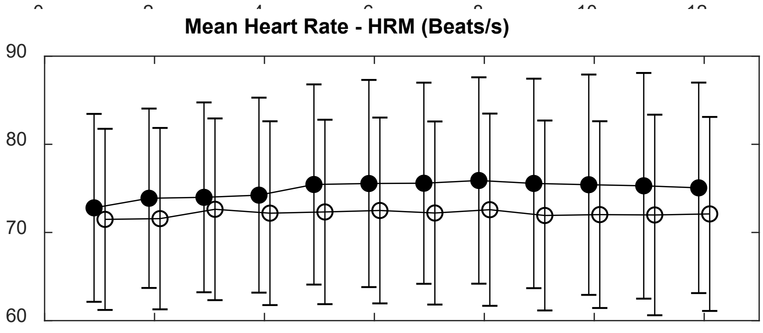
According to Fig 1 (a), HRR increased significantly in both groups as TOT segments increased, Fig 1 (a), $F(4.9,167.1) = 8.4, p < .001, \eta_p^2 = .2$. No interaction between TOT segments and groups was found in HRR. However, there was a significant difference between groups in HRR, $F(1,34) = 19.6, p < .001, \eta_p^2 = .4$. There was a tendency to increase in HRM with increase in TOT segments in both young and elderly groups, $F(2.9,100.9) = 2.6, p = .059, \eta_p^2 = .1$, Fig 1 (b). No difference between groups was found in HRM.

The performance fluctuated in the young group and increased in the elderly group with the increasing TOT, Fig 1 (c), $F(11,374) = 4.0, p < .001, \eta_p^2 = .1$. There was no interaction of the performance between the TOT segments and groups. There was a significant difference in the performance between groups, $F(1,34) = 32.8, p < .001, \eta_p^2 = .5$.

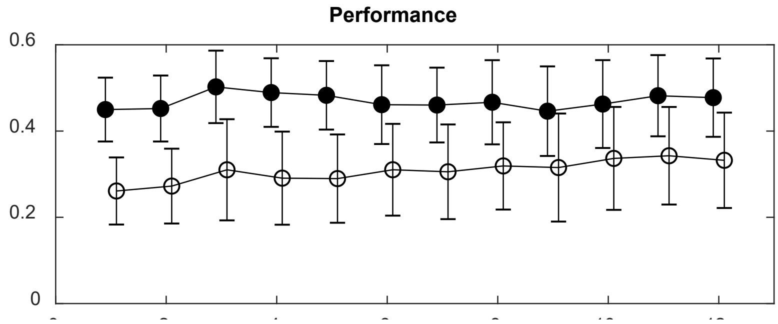
According to Fig 1 (d), KSS increased with the increase in TOT segments in both groups, $F(1.8,59.9) = 12.8, p < .001, \eta_p^2 = .3$. There was no interaction between TOT segments and groups in KSS. No significant difference between groups was observed in KSS. In addition, Mental fatigue ratings increased significantly from its baseline value in both young and elderly groups, $p < .001$.



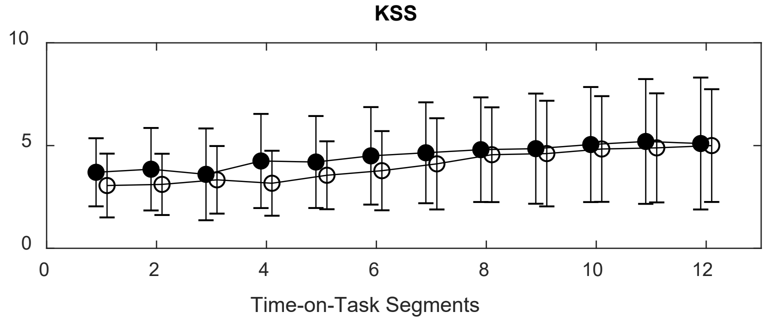

(a)




(b)




(c)




(d)

**Fig. 1.** The illustration of mean and standard deviation of (a) HRR, (b) HRM, (c) Performance, and (d) KSS in the young and elderly groups for each time-on-task (TOT) segment.

## 4 Conclusion

The results showed that HRR was sensitive to fatigue development. The performance and perceived mental fatigue changed in concordance with increasing TOT segments. This, in sum, lends support to the possibility of using the HRR as an index to detect fatigue development in computer work in young and elderly individuals.

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