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Systematic Analysis of Dynamic Association of Health Outcomes with Computer Usage for Office Staff

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***Abstract*—**This paper systematically investigates the time-dependent health outcomes for office staff during computer work using the developed mathematical model. The model describes time-dependent health outcomes in multiple body regions associated with computer usage. The association is explicitly presented with a dose-response relationship which is parametrized by body region parameters. Using the developed model we perform extensive investigations of the health outcomes statically and dynamically. We compare the risk body regions and provide various severity rankings of the discomfort rate changes with respect to computer-related workload dynamically for the study population. Application of the developed model reveals a wide range of findings. Such broad spectrum of investigations in a single report literature is lacking. Based upon the model analysis, it is discovered that the highest average severity level of the discomfort exists in neck, shoulder, eyes, shoulder joint/upper arm, upper back, low back and head etc. The biggest weekly changes of discomfort rates are in eyes, neck, head, shoulder, shoulder joint/upper arm and upper back etc. The fastest discomfort rate is found in neck, followed by shoulder, eyes, head, shoulder joint/upper arm and upper back etc. Most of our findings are consistent with the literature, which demonstrates that the developed model and results are applicable and valuable and can be utilized to assess correlation between the amount of computer-related workload and health risk.

***Keywords*—**Computer-related workload, health outcomes, dynamic association, dose-response relationship, systematic analysis.

I. Introduction

MILLIONS of people spend hours in front of computers everyday. Working with computer for whole day is not rare. It is no wonder that computer-related health problems have also increased dramatically. These problems are caused by sitting for prolonged periods of time which are linked to increased stress of the back, neck, arms and even legs as well as visual stress. It has been well documented that work-related musculoskeletal disorders (MSDs), repetitive strain injury (RSI) and teary eyes are related to prolonged computer use [1]-[4]. Though there is an extensive literature on this topic in recent decades, two general analysis model specifications can be identified: statistical risk models and biomechanical models.

Biomechanical models are used to study human musculoskeletal systems. During computer work, no high muscular forces are needed and the postures are fairly constant. Thus the main factor for the daily biomechanical load is the cumulative duration of the computer-related workload. However, the mechanism of musculoskeletal pain underlying low level static exertions is poorly understood [5], even though there is good evidence supporting a biomechanical pathogenesis for MSDs. Therefore, statistical risk factor models are the dominant methodologies. Whilst many research results have been published on risk factor topics, rigorous and consistent solutions are still elusive [1]. There is also a lack of studies on the dynamic process of health outcomes associated with computer-related workload as an exposure. As pointed out before, the duration and frequency of computer usage are a very important major index for describing continuous and intensive computer workload for computer works underlying low level static exertions which are obviously dynamic variables. It is therefore important to study the dynamic behavior of the relationships between computer-related workload and health outcomes. To fill the gap in literature, we analyze the dynamic behavior of health outcomes represented by musculoskeletal, vision and moods discomfort ratings under the computer-related workload assessed by counting keyboard and mouse clicks through an electronic device with a special program.

The health outcomes data were collected from office staff temporally in Finland who did office work for at least four hours a day and reported a moderate amount of musculoskeletal or vision symptoms. Based on the dynamic data, a dose-response function was obtained to indicate the nonlinear relation between computer-related workload and health outcomes presented as discomfort ratings [6]. The present study is an extension of some previous results [7]. We aim to use this model to assess the impact of computer-related work exposure on musculoskeletal, vision and mood discomfort ratings in 15 different body regions for office staff in order to better understand and prevent computer-related health problems and disorders.

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II. Applied Data and Models

A. Data

The subjects in this paper (n = 103) were office staff in Finland who did office work for at least four hours a day and reported a moderate amount of either musculoskeletal or sensory or both symptoms. The health outcomes were evaluated through self-administered questionnaire-diaries which consisted of items presenting localization of musculoskeletal, vision and mood discomfort for 15 body parts including head, eyes, neck, shoulder, arms and almost all over. Each item was scored as 1 to 5 according to the discomfort severity such as "5-feel good" and "1-feel very uncomfortable". The subjects were requested to fill in the diaries three times a day. Information on computer-related workload was assessed through measurement device by counting keyboard and mouse clicks continuously monitoring with a time accuracy of 10 milliseconds with a special program (Work-Pace™, Niche Software Limited, New Zealand). Data were then summed up for a daily base. Detailed description of the data can be found in [8].

B. Mathematical Model

Due to a large portion of missing data for some subjects because of both technical and human factors, the study population included 69 subjects finally and a weekly model was selected as model specification [6]. Another very important reason why we decided to average the data to use a weekly model was that we believe that long-term variations of health outcomes can be superimposed to changes in weekly patterns owing to the weekend breaks. Moreover, the responses of discomfort ratings were treated as continuous variables since they have continuous properties and distribution and there is no computation restriction against fitting continuous models to ordinal data. In both clinical trials and social epidemiology for example, investigators often need to deal with underlying continuous responses that are recorded as ordinal variables such as in our dataset. It is of course possible that a continuous model may not be appropriate to ordinal outcomes even though it can fit the ordinal data in some special cases. In our data, variables are continuous in nature and it is appropriate to treat them as continuous variable even though outcomes are ordinal due to the insufficient performance of measurement.

Based on the modelling work [6], a linear relationship was found between time and computer-related workload and a dose-response relationship was identified between time and health outcomes. Overall, a dose-response functional relationship is obtained between computer-related workload and health outcomes as the computer-related workload depends linearly on the time variable.

The developed explicit model equations can be expressed with the following general functional form as

$$\overline{a}(t) = (\alpha_1 + \frac{\alpha_2 - \alpha_1}{1+10^{t-\alpha_3}}) + \text{error-term} \qquad (1)$$

where $\overline{a}(t)$ presents the time-dependent health outcomes or discomfort measures, presented as discomfort ratings, ranged from 1 to 5 and α_1, α_2, α_3 are body region, vision and mood dependent parameters. Equation (1) is parametrized by body region, vision and mood dependent parameters.

Using commercialized statistical software package SAS (PROC NLMIXED), we can compute the standard errors of the estimates in (1). PROC NLMIXED addresses the sequential correlation issue directly by modelling the covariance structure. As a single dose-response model can not be fit to all the curves, the mood outcomes are modelled separately with an extra exponential function represented through two extra parameters which are not statistically significant at the 5 percent probability level, however. So the extra parameters are eliminated. Table I displays the model estimates for the parameters in $\overline{a}(t)$ based on 15 different body locations.

TABLE I
Fitted Parameters in (1) for 15 Different Body Locations (SE-Standard Error)

Body regions	a_1 (SE)	a_2(SE)	a_3(SE)
head	3.87^{***}(0.08)	4.00^{***} (0.08)	2.63^{***}(0.38)
eyes	3.72^{***}(0.09)	3.89^{***}(0.10)	2.29^{***}(0.49)
neck	3.58^{***}(0.10)	3.74^{***}(0.10)	2.19^{***}(0.38)
shoulder	3.64^{***}(0.10)	3.77^{***}(0.10)	2.25^{***}(0.39)
shoulder joint/upper arm	3.75^{***}(0.10)	3.87^{***}(0.10)	2.63^{***}(0.48)
forearm	4.02^{***}(0.10)	4.07^{***}(0.10)	3.15^{**}(1.33)
wrist	4.02^{***}(0.10)	4.09^{***}(0.10)	3.73^{***}(0.65)
fingers	3.99^{***}(0.11)	4.07^{***}(0.11)	3.83^{***}(0.41)
upper back	3.75^{***}(0.11)	3.87^{***}(0.11)	2.78^{***}(0.38)
low back	3.84^{***}(0.11)	3.89^{***}(0.11)	3.43^{***}(1.06)
hips	4.29^{***}(0.09)	4.30^{***}(0.09)	3.51^{***}(1.24)
thighs	4.30^{***}(0.09)	4.32^{***}(0.10)	3.44^{***}(1.37)
knees/shin	4.21^{***}(0.11)	4.26^{***}(0.11)	3.72^{***}(0.63)
feet	4.18^{***}(0.10)	4.23^{***}(0.10)	4.14^{***}(0.93)
mood	4.04^{***}(0.79)	3.57^{***}(0.49)	2.88^{***}(0.39)

$^{***}p<0.001$, $^{**}p<0.05$

III. Analysis Results

A. Average Ranking of Discomfort Severities

We perform two Waller-Duncan *k*-ratio *t* tests on $\overline{a}(t)$ for detailed contrast of the average discomfort ratings of the health outcomes. This testing is for multiple means comparison which demonstrates the average ranks of discomfort severities. Therefore, the testing probably has too rough classification results for nonlinear and dynamic data. More detailed classification will be given in the following sections. Table II shows the summarized results.

The results show that the average severity levels of discomfort can be grouped into the following categories roughly from severe to moderate as level 1: neck and shoulder; level 2: eyes, shoulder joint/upper arm and upper back; level 3: low back and head; level 4: fingers, forearm and wrist; level 5: feet, knees/shin, hips and thighs; level 6: mood.

TABLE II
AVERAGE RANKING OF DISCOMFORT SEVERITIES FOR DIFFERENT LOCATIONS

Waller Grouping	Mean	Locations
6	4.58	mood
5	4.31	thighs
5	4.30	hips
5	4.24	knees/shin
5	4.22	feet
4	4.07	wrist
4	4.05	forearm
4	4.04	fingers
3	3.93	head
3	3.87	low back
2	3.80	upper back
2	3.80	shoulder joint/upper arm
2	3.78	eyes
1	3.67	shoulders
1	3.63	neck

B. Average Weekly Changing of Discomfort Severities

Regarding to weekly severity changes over time, Table III demonstrates some of the elementary evaluations: weekly change rate and weekly change with respect to initial discomfort rate. Using these two parameters, we perform another Waller-Duncan *k*-ratio *t* test and the results show that the dynamic changes of discomfort ratings can be grouped into two categories: • bigger change group: mood, neck, eyes, head, shoulder, shoulder joint/upper arm and upper back; • smaller change group: fingers, wrist, low back, forearm, knees/shin, feet, thighs and hips. This result implies that computer-related workload is more likely to be associated with upper extremity symptoms.

C. Dynamic Weekly Changing of Discomfort Severities

As the model parameters of the dose-response relation (1) have biological meanings, we give meaningful biological interpretations in this section.

Firstly, a_3 in (1) describes the halfway result of the discomfort ratings from Monday (t = 1) to Friday (t = 5). Take the body region 'neck' as an example, Table I shows that at 2.19 days the discomfort level is half of the levels at Monday and Friday which presents the minimum value. This means that neck gets tired much quicker than other body regions. The halfway results of the studied body regions in increasing order are: neck (2.19 days), shoulder (2.25 days), eyes (2.29 days), head (2.63 days), shoulder joint/upper arm (2.63 days), upper back (2.78 days), mood (2.88 days), forearm (3.15 days), low back (3.43 days), thighs (3.44 days), hips (3.51 days), knees/shin (3.72 days), wrist (3.73 days), fingers (3.83 days) and feet (4.14 days).

The order is consistent with Table II and many published reports. Note that such halfway outcome for feet appears at the day 4.14 which means that no discomfort or a little discomfort was developed in feet among the study subjects.

Secondly, for the changes of discomfort ratings during the working week presented as a_2 - a_1, the discomfort rating for eyes decreases maxima unit of 0.17. This means the resulting weekly discomfort appear to be maximum in eyes. More results of such evaluations are illustrated in Table IV. The decreased units of discomfort ratings in descending order are: eyes (0.17), neck (0.16), head (0.13), shoulder (0.13), shoulder joint/upper arm (0.12), upper back (0.12), fingers (0.08), wrist (0.07), low back (0.05), forearm (0.05), knees/shin (0.05), feet (0.05), thighs (0.02), hips (0.01) and mood (-0.47).

An interesting result is obtained for the discomfort rating 'mood' with negative sign which means that the discomfort severity of mood decreases during the week. The office staff tended to be in much better moods during the weekend Friday. The result seems to be rational based on our common knowledge.

TABLE III
VALUES OF DYNAMIC MEASURES FOR HEALTH OUTCOMES IN DIFFERENT LOCATIONS; TIME PERIOD IS ONE WEEK

Body regions	Weekly change	Weekly change/initial discomfort rating
head	0.126	0.032
eyes	0.126	0.042
neck	0.150	0.040
shoulder	0.123	0.033
shoulder joint/upper arm	0.117	0.030
forearm	0.049	0.012
wrist	0.066	0.016
fingers	0.075	0.018
upper back	0.117	0.030
low back	0.049	0.012
hips	0.010	0.002
thighs	0.019	0.004
knees/shin	0.047	0.011
feet	0.044	0.010
mood	0.948	0.019

TABLE IV
VALUES OF DYNAMIC CHANGES FOR HEALTH OUTCOME DISCOMFORT IN DIFFERENT LOCATIONS; TIME PERIOD IS ONE WEEK

Body regions	a_2 - a_1
head	0.13
eyes	0.17
neck	0.16
shoulder	0.13
shoulder joint/upper arm	0.12
forearm	0.05
wrist	0.07
fingers	0.08
upper back	0.12
low back	0.05
hips	0.01
thighs	0.02
knees/shin	0.05
feet	0.05
mood	-0.47

D. More Findings of the Dynamic Weekly Changing of Discomfort Severities

Take the body regions 'neck' and 'eyes' as an example, we can find that the faster fatigue rate is discovered in neck, however eyes has the largest discomfort change over weekly time due to the nonlinearity of the week change for discomfort rates (see Section III/C). This implies that the fatigue rate is faster in neck at the beginning of the week and gradually slows down over the week, or in another word the fatigue rate of eyes is faster at the end of week when comparing neck and eyes. This conclusion is also valid to the discomfort ratings of the following body site pairs with the same dynamic behavior: shoulder and eyes, see some examples displayed in Table V.

TABLE V
SCHEMATIC COMPARISON OF THE DYNAMIC CHANGES FOR HEALTH OUTCOMES IN DIFFERENT BODY REGIONS; TIME PERIOD IS ONE WEEK

Faster fatigue change in early week	Faster fatigue change in late week
neck	eyes
shoulders	eyes
shoulders	head
forearm	low back
low back, forearm	fingers, wrist
thighs	fingers, wrist, knees/shin, feet
hip	fingers, wrist, knees/shin, feet

IV. CONCLUSION

The primary aim in this paper is to analyze mainly dynamic changes of health outcomes in response to computer-related workload among the office workers using our developed nonlinear model. The health outcomes, represented as discomfort ratings, in head, eyes, neck, shoulder, arms and almost all body regions are analyzed systematically and the model implications are examined. As the association of the health outcomes and computer-related workload is identified as dose-response relationship, the severity levels and temporal changes of health outcomes are analyzed based on the body regions dynamically. It is obvious that analysis of cross-sectional data, which is the most common technique in such research, cannot provide such broad findings especially related to dynamic changes.

In a review of the literature, we did not find any single report that covers such broad spectrum of investigations. Furthermore, most of our findings are consistent with the literature ([4], [9], [10]). These identified findings can lead us to characterize health outcome evolution in relation with computer-related work, thus helping to prevent computer-related health problems.

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