PERSONAL FITTING PROCEDURE FOR CYCLE ERGOMETER WORKLOAD CONTROL BY ARTIFICIAL NEURAL NETWORKS

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Abstract-The Internet technology was introduced to provide on-demand support for fitting the cycle ergometer workload personally depending on each individual’s physical work capacity. It was useful to combine the ratings of perceived exertion (RPE) with objective physiological indices during the exercise. We estimated the RPE from objective indices (i.e., muscular fatigue-related indices and the heart rate), using a feed-forward type artificial neural network. Interpreting the estimation errors was useful to design an appropriate workload for an individual elderly person.

Keywords - cycle ergometer, heart rate, muscle activity, ratings of perceived exertion, artificial neural network
Purpose

Social Background
- progression of aged society
- high motivation for health

However
- physical work capacity
  - risk for overuse
  - degeneration of functions
  - large individual differences

Health Promotion by Exercise
"Wellness"

IT system
to support Exercise for Wellness

Web-based Healthcare System
Internet-based Cycle Ergometer System for Serving Personally Fitted Workload

Exercise at any time and at any location

Browsing by Java made programs

Wellness Bike

measurement & control unit

Home

Internet

Sports Gymnasium

Health Care Center

HR sensor

Ref. electrode

Active 4-bar electrode

paddle sensor

measurement & control unit

Touch panel

Communication port

Zoom Up

Internet

Network server

Personal database

PC for maintenance & service

support center

measured data

control info.

analyzed results

Monitoring fuzzy parameters
If necessary

For control

Continuously Supporting
at any time and at any location

PC for maintenance & service

6/a6fK?DF=/a6eA/a6c

amp.network

2AHI/a6f/a6e=/a6c@=J=>=IA

Internet-based Cycle Ergometer System for Serving Personally Fitted Workload

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### Estimation of Total fatigue index

\[ \delta = \sum_{i=1}^{n} \left( SEMG, \ HR \right) \]

\[ W_{L_n+1} = W_{L_n} - \delta \cdot \Delta W_L \]

- \( W_{L_n} \): workload at \( n \)-th frame
- \( \Delta W_L \): incremental step of workload
- \( \delta \): fatigue index

**Recursive Workload Control**

- **Surface EMG(SEMG)**
  - amplitude info
  - frequency-related info.

- **Heart Rate (HR)**

- **Fuzzy control**
  - Fuzzy Rules
  - Membership Functions

**Workload control**

**Control by Objective Indices**

**Time**

**Controlled workload**

**AT**
Objective Indices

**Surface Myoelectric Signals**

**Amplitude index**

\[ ARV(m) = \frac{1}{N} \sum_{k=m}^{m+N-1} |emg(k)| \]

**Frequency index**

\[ MPF(m) = \frac{\sum_{f=f_L}^{f_H} f \cdot P(m, f)}{\sum_{f=f_L}^{f_H} P(m, f)} \]

**Muscular fatigue index**

\[ \gamma_{ARV-MPF} \]

**Heart Rate**

\[ HR \]

\[ m : \text{frame number} \]
\[ N : \text{number of samples in a frame} \]
\[ emg : \text{samples of ME signals} \]
\[ P(m, f) : \text{power spectrum of ME signal at } m\text{-th frame} \]
\[ f_H : \text{high-frequency limit for estimation} \]
\[ f_L : \text{low-frequency limit for estimation} \]

1 frame = 5 sec
Segmentation in HR-$\gamma_{\text{ARV-MPF}}$ Scatter Graph

1) Weigh the random values for each sample,
2) Estimate the center of samples by fuzzy means, and tentatively segment the samples,
3) Change the weight based on the distances between the center and each sample,
4) Repeat steps 1) - 3) until the center position reaches a steady point, and then
5) Divide the samples.

$\mu_1, \mu_2, \mu_3$: mean at each segment
$\sigma_1, \sigma_2, \sigma_3$: s.d. at each segment
Changes in HR-$\gamma_{\text{ARV-MPF}}$ Scatter Graph

(a) first set
April, 2000

(b) fourth set
November, 2000

Type A

deviation

subject TH (a 70-year-old man)

progressively increasing workload

seven months

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Objective / Subjective Representation of Fatigue

**Objective Data**
- myoelectric signals
- electrocardiogram

**Subjective Representation**

<table>
<thead>
<tr>
<th>RPE-Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Very, very light</td>
</tr>
<tr>
<td>8</td>
<td>Very light</td>
</tr>
<tr>
<td>9</td>
<td>Fairly light</td>
</tr>
<tr>
<td>10</td>
<td>Somewhat light</td>
</tr>
<tr>
<td>11</td>
<td>Hard</td>
</tr>
<tr>
<td>12</td>
<td>Very hard</td>
</tr>
<tr>
<td>13</td>
<td>Very, very hard</td>
</tr>
</tbody>
</table>

RPE (Ratings of Perceived Exertion) by Borg (Med. Sci. Sports Exerc. 1973)
Workload Adjustment Procedure

Design of Control Parameters
- Fuzzy Rules
- Membership Functions

PIW : Progressively Increasing Workload
CW : Controlled Workload

Key points
- classification
- segmentation

Key point
- Personal Fitting
Evaluation of Personal Fitting Procedure

\[ \varepsilon(n) = RPE(n) - \hat{RPE}(n) \]

- Subjective indices
- Objective indices
- Estimation error

Estimation of RPE by Artificial Neural Network
Selection of a suitable ANN

Numbers of cells at each layer were 4 at the input, 4 - 20 at the middle, and 1 at the output (the total number of ANNs checked was 25).

\[ \epsilon(n) = RPE(n) - \hat{RPE}(n) \]

minimum squared error

A suitable ANN for personal fitted workload control
Experimental Conditions

- **Subjects**
  18 senior subjects (63.5±7.5 years old)
  *from September 2000 to March 2001 every 2 months*
  6 senior subjects (69.3±4.1 years old)
  *from November 2001 to December 2001 every 2 weeks*

- **Myoelectric Signals**
  muscles: right leg vastus lateralis
  gain: 60dB
  frequency band width: 5.3Hz - 1.2kHz
  4-bar active array electrode

- **Heart Rate**
  LED-photo transistor

- **Metabolism**
  lactate in blood every minute
  respiration gas exchange every minute

- **Subjective Index**
  ratings of perceived exertion (RPE)
Workload Design for Personal Fitting

**Temporary Increasing Workload**

How to determine:
- level
- timing

Little bit hard exercise and perception of workload changes

Protocol for Exercise

**AT**: Anaerobic Threshold

Conventional WL control

\[
WL_{\text{min}} = 70\%WL_{AT}
\]

\[
WL_{\text{max}} = 130\%WL_{AT}
\]
**Sufficient Workload Control**

- **Sufficient example for PF**

Subject KY

- **Type-A**, 73-years-old man
- **WL_{AT} = 97 W, WL_{LT} = 120 W**
- HR around AT
- No severer muscular fatigue

**Figure 1:**
- WL [W] vs. time [frame]
- RPE vs. time [frame]
- HR [bpm] vs. time [frame]
- α vs. time [frame]

**Graphs:**
- WL [W] values range from 0 to 150 W.
- RPE values range from 0 to 20.
- HR values range from 60 to 120 bpm.
- γ values range from -1 to 1.

**Notes:**
- WL_{AT} = 97 W, WL_{LT} = 120 W
- Subject KY

**Reference:**
- PERSONAL FITTING PROCEDURE FOR CYCLE ERGOMETER WORKLOAD CONTROL BY ARTIFICIAL NEURAL NETWORKS
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Insufficient Levels and Timing

Insufficient example for PF

Subject KY
HR-γ_{ARV-MPF} Scatter Graphs in PF

(a) subj. A, Nov 11, 2001

20.1% Lighter than PIW

(b) subj. A, Dec 9, 2001

16.6% Relatively light for muscles, but hard for respiration

(c) subj. A, Dec 23, 2001

33.2% Appropriate exercise, comfortable

- HR around AT
- No severer muscular fatigue

Insufficient level
Insufficient timing
sufficient workload control

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RPE-Workload Scatter Graph at Personally Fitted Trial

Type-A, 73-years-old man
\( W_{LAT} = 97 \text{ W}, \ W_{LT} = 120 \text{ W} \)

\[ \varepsilon(n) = RPE(n) - \hat{RPE}(n) \]

2001, Dec. 23   Subject KY
Conclusions

1. The fuzzy rules and membership functions were designed based on the individual’s physical work capacity.

2. Using a feed-forward type artificial neural network, we estimated the RPE (i.e., a subjective index) from the HR and muscular fatigue, and studied the balance between the objective and subjective representations of fatigue.

3. The gap was suitable to determine the appropriate levels and the timing of temporally inserting workloads in a basic workload variation.
Conclusions (continued)

Personally Fitting Procedure

1. Evaluation of basic data under progressively increasing workload.

2. Continuously changing the intensity and timing of temporary increasing workloads.

3. Comparison between subjective index (RPE) and objective indices by ANN.
   - small error between RPE and estimated RPE.
   - RPE greater than 13 and no progression of muscular fatigue.

Wellness Bike for Home-Based Exercise