Energy Cost of Bimanual Cranking; Difference between Two Motion Patterns

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Oxygen consumption during driving of an arm crank ergometer with symmetric and reciprocal motions was measured in 10 healthy young and 10 healthy elderly subjects. Oxygen consumption during driving with reciprocal motion was lower than that with symmetric motion and the ratio of energy-cost between the two motion patterns was not found to be different for the two groups. It is assumed that the late-appearing and matured motion-patterns are more efficient in terms of energy cost than the early-appearing and primitive ones.

According to a principle of motion economy related to the use of the human body, motions of the arms should be simultaneously made in symmetric directions, since the symmetric motions of the arms tend to balance each other reducing the shock and jar on the body and enabling the subject to perform his task with less mental and physical effort (cf., Barnes, 1968). Studies of reaction time (RT), and regularity and speed of movements in bimanual tasks have supported this principle, i.e.: (1) RTs of symmetric motions are faster than those of opposite motions (Taniguchi et al., 1977); (2) the performance of bimanual tasks is more regular in symmetric motions than in asymmetric ones (Cohen, 1971); and (3) in tasks requiring simple repetitive movements, bimanual asymmetric motions tend to be slower than symmetric ones (Annett and Sheridan, 1973; Wyke, 1969). However, there are exceptional tasks which do not follow this principle; for instance, bimanual cranking is usually performed with bilateral reciprocal motion of the arms. Symmetric arm motion is accompanied by flexion and extension of the trunk, whereas reciprocal motion by rotation of the trunk. Assuming that

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trunkal movements accompanied by the symmetric motion of the arms require high physiological cost and subjects choose a motion-pattern easy to perform, the principle of motion economy in terms of energy cost may hold also in bimanual cranking, i.e., reciprocal motion is less energy-consuming than symmetric motion.

To confirm this assumption, we examined oxygen consumption during driving of an arm crank ergometer with symmetric or reciprocal motion of the arms.

METHODS

Ten young and 10 elderly male subjects participated in the study (Table 1). The subjects' tasks were to drive a bicycle ergometer (EM 370, Elema-Schönandar) with the cranks in the same or opposite phase by symmetric or reciprocal motion of the arms respectively. The subject sat on a chair in front of the bicycle. The position of the chair was adjusted for each subject so that the shoulders had 70 degrees flexion with the elbows fully extended. The rate of pedalling was 50 rpm, and the load 20 W for the young and 10 W for the elderly. Half of the subjects in each group performed firstly the task with symmetric motion for 4 min after 5 min rest sitting on the chair. Then, after 5 min rest, the task with reciprocal motion was performed for 4 min. The remaining subjects of each group did the tasks in reverse order. The expired gas was collected in a Douglas bag for the last 2 min during the first resting session and for the last 1 min during successive sessions, and was subsequently analyzed using a mass meter (Medical Gas Analyzer MAG-110, Perkin Elmer).

Table 1. Means and SDs of age, weight and height for each group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Young</th>
<th>Elderly</th>
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<tbody>
<tr>
<td>age (yr)</td>
<td>22.3±2.9 (19–27)</td>
<td>73.4±4.8 (68–85)</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>64.5±6.6 (57–76)</td>
<td>52.2±5.9 (46–64)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>169.4±4.8 (162–178)</td>
<td>154.9±5.6 (149–166)</td>
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Table 2. Means and SDs of oxygen consumption, gross efficiency and net efficiency during ergometer driving.

<table>
<thead>
<tr>
<th>Group</th>
<th>Young</th>
<th>Elderly</th>
</tr>
</thead>
<tbody>
<tr>
<td>rest $\dot{V}O_2$ (ml/min/kg)</td>
<td>3.8±0.4</td>
<td>3.8±0.5</td>
</tr>
<tr>
<td>$\dot{V}O_2$ (ml/min/kg)</td>
<td>9.3±1.0*</td>
<td>8.7±0.9</td>
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<tr>
<td>gross efficiency (%)</td>
<td>9.7±1.2*</td>
<td>10.4±1.4</td>
</tr>
<tr>
<td>net efficiency (%)</td>
<td>16.6±2.8*</td>
<td>18.8±3.7</td>
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* Significantly different from reciprocal, $p<0.05$. 
ENERGY COST OF BIMANUAL CRANKING

RESULTS

Table 2 shows overall means and SDs of oxygen consumption, and gross and net efficiency for the two motions in each group. The energy cost of symmetric motion was significantly higher compared to reciprocal motion for both groups. The ratio of gross efficiency of symmetric motion to reciprocal was calculated for each group to compare the age-related difference of efficiencies between the two motions. The rate was $1.07 \pm 0.08$ for the young and $1.08 \pm 0.07$ for the elderly. There was no significant difference of the ratio between the two groups.

DISCUSSION

The present results indicate that the energy-cost required to drive the arm crank ergometer as estimated by oxygen consumption was higher when performed with symmetric motion of the arms than with reciprocal motion, and that the ratio of energy-cost between the two motion patterns was not different for the two groups. Kinematic analysis during arm cranking motions showed larger body-sway in symmetric motions than in reciprocal (MARUYAMA et al., 1987). The reduced efficiency of symmetric motion would be due to this body-sway.

Although the range of trunkal rotation (IWASAKI et al., 1984) and motor skills are deteriorating in the elderly, the superiority of reciprocal motion for energy cost in the arm cranking task was well preserved in healthy elderly people. The symmetric motions of the arms appear phylogenetically and ontogenetically early compared to reciprocal motions (NAKAMURA et al., 1970; PAGE, 1967). The present results imply that motion-patterns appearing late in the developmental sequence consume less energy than motion-patterns appearing early, the same task being performed. According to MARUYAMA et al. (1986), oxygen consumption during floor crawling is highest with a homologous pattern of limb-movements, lowest with a reciprocal one, and intermediate with a homolateral pattern, showing that the developmental sequence of crawling patterns follows the principle of motion economy in terms of energy cost. It is assumed that the late-appearing and matured motion-patterns are more efficient than the early-appearing and primitive ones not only in their performance level but also in energy cost.

REFERENCES


