Physiological responses to asynchronous and synchronous arm-cranking exercise

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Abstract The purpose of this study was to examine mechanical efficiency (ME) and physiological responses during asynchronous (the pedal arms oriented in opposing directions) arm-cranking exercise (AACE) and compare these responses to those obtained during synchronous (the pedal arms oriented in the same direction) arm-cranking exercise (SACE). Ten male subjects participated in the study and performed two exercise tests, one AACE and the other SACE in counterbalanced order. Each test consisted of submaximal (30, 60 and 90 W) and maximal exercise. At 30 W, gross ME was significantly lower during SACE compared to AACE, whereas at 60 W and 90 W no differences between the two types of exercise could be observed. We found that at lower power output levels the flywheel mass and its moment of inertia may have induced more body movements for compensation, which may have been more pronounced during SACE than during AACE. At higher levels of power output this flywheel mass effect was less, which explained the lack of differences in ME at these levels. Physiological responses to maximal AACE or SACE exercise were not significantly different. The results indicated that there were no differences in physiological responses to AACE and SACE exercise at higher exercise intensities. However, at lower levels of power output ME seemed to decrease, most likely as a result of the flywheel-mass effect, which was more pronounced during SACE.

Key words Upper body exercise • Maximal exercise • Submaximal exercise • Gross mechanical efficiency

Introduction

Since many industrial tasks and rehabilitation programmes involve the use of the upper part of the body, an increasing interest in upper-body exercise can be noticed in occupational and rehabilitation medicine as well as in laboratory tests (Franklin 1985; Kemper et al. 1990; Shephard 1991; Casaburi et al. 1992; Davis 1993). In addition, wheelchair-dependent individuals have to turn to upper-body exercise for daily ambulation. Recently, several studies have been directed towards physiological responses during upper-body exercise, i.e. in pulmonary patients (Carter et al. 1992), in cardiac patients (Franklin 1989), in individuals with a spinal-cord injury (Hopman et al. 1992), during wheelchair propulsion (Van Der Woude et al. 1988) and in comparison to lower-limb exercise (Sawka 1986).

Up to the present, however, no study has been directed towards the examination of the physiological responses of different types of arm-cranking exercise, i.e. asynchronous and synchronous arm-cranking. During asynchronous arm-cranking exercise (AACE) the pedal arms of the flywheel are oriented in opposing directions 180° relative to each other, which is the most common situation for arm-cranking exercise in laboratory or clinical tests. During synchronous arm-cranking exercise (SACE) the pedal arms are oriented in the same direction, 0° relative to each other, which is of interest for wheelchair propulsion. This study was conducted because it is important, for routine laboratory and clinical cardiorespiratory assessment as well as for daily ambulation of wheelchair dependent people, to clarify the differences between the mechanical efficiencies and physiological responses of these two types of exercise.

The purpose of this study was, therefore, to examine the differences in physiological responses between maximal AACE and SACE, and, in addition, to establish mechanical efficiency (ME) during different intensity levels of submaximal AACE and SACE.

Methods

Subjects

Ten male able-bodied subjects participated in this study after giving their written informed consent. The study was approved by
the Faculty Ethics Committee. All the subjects were healthy, used
no medication and their activity levels varied from hardly any ex-
ercise to highly trained individuals.

Protocol

The subjects visited the laboratory twice within 1 week and per-
formed submaximal and maximal arm exercise (Fig. 1). Submaxi-
mal exercise was performed at 30 W, 60 W and 90 W. Each period
of exercise lasted 5 min with a 6-min recovery period in-between.

Sub maximal exercise was followed by a maximal exercise test. Power
output increased every minute by 10 W until exhaustion, with a crank
revolution frequency of 65 rpm (Washburn and Seals 1983). The test was concluded when, even after verbal encourage-
ment by the examiner, the revolutions per minute fell below 60."Heart rate (HR) above 170 beats-min⁻¹ and respiratory ex-
change ratio (R) above 1.00 were used as objective criteria for
maximal exercise (Sawka 1986). The participants were only in-
formed about the performances achieved after the second test. The
tests were performed once with synchronous and once with
asynchronous arm cranking. Each type of test was assigned in
random order, using a counterbalanced design. On all occasions,
temperature in the experimental room was maintained between
20 and 22 °C with a relative humidity of 50%-60%.

Apparatus

Exercise was performed using an electro-magnetic arm ergometer
(type Angio, Lode, Groningen, The Netherlands). The subjects
sat on a stool and the axis of the arm-crank ergometer was ad-
justed to shoulder level (Sawka 1986). The feet were positioned
on the ground at premarked places to maintain high reproducibil-
ity of the posture of the subjects.

During AACE, the pedal arms of the flywheel were oriented
during the second test whereas HRpeak and Rpeak
using surface electrodes. Measurements were used as a qualitative
indication for muscle activity during the different types of exer-
cise. The gross ME was calculated during submaximal steady-state
exercise by dividing the internally liberated mechanical power,
which was assumed to be equal to VO₂, into external power out-
put (W): ME = W/(VO₂ × 340), in which 340 W has been shown to
be the power equivalent for 1 l O₂-min⁻¹ (Gaesser and Brooks
1975; Stainsby et al. 1980; Van Der Woude et al. 1988; Linden et
al. 1993).

Results

A paired Student's t-test was applied to assess the significance of
differences in the physiological responses between AACE and
SACE during maximal and submaximal exercise. A two-tailed
p<0.05 was considered to be statistically significant.

Table 1 presents the physiological responses to max-
imal AACE and SACE. All the subjects met at least
one of the two criteria for maximal performance, so
their efforts can be considered to be maximal. No sig-
nificant differences were found in the peak power out-
put (Wpeak), peak oxygen uptake (VO₂peak), peak heart
rate (HRpeak) and peak respiratory exchange ratio
(Rpeak) between AACE and SACE.

During submaximal exercise the ME was significant-
different between AACE and SACE at the 30-W ex-
ercise intensity. At 60 and 90 W, however, no signifi-
cant differences in ME were noted between AACE and
SACE (Fig. 3).

Table 2 presents the peak responses for test 1 and
test 2. The Wpeak and VO₂peak were significantly higher
during the second test whereas HRpeak and Rpeak

![Fig. 1](image1) The exercise protocol, including submaximal (submax) and maximal exercise (max test)

![Fig. 2](image2) The two types of arm-cranking exercise performed in this study: asynchronous arm cranking exercise (AACE) and synchronous arm cranking exercise (SACE)
showed no differences between the first and the second test. No significant differences were observed in ME between test 1 and test 2.

**Discussion**

Whereas previous research has in the main been directed towards the examination of physiological responses to arm-cranking exercise (ACE) and wheelchair propulsion (Van der Woude et al. 1988; Linden et al. 1993), in the present study attention has been focused on two different forms of arm-cranking exercise, i.e., asynchronous versus synchronous, which is of interest for wheelchair propulsion as well as for laboratory tests.

The values of gross ME found in the present study (Table 2) are in agreement with previously reported values during ACE in able-bodied subjects (Cummins and Giddon 1983; Powers et al. 1984; Hopman et al. 1992). Results have indicated that ACE has a higher ME compared to hand-rim wheelchair propulsion (11%–15% vs 8%–10%, respectively; Van der Woude et al. 1988). Linden et al. (1993) have reported even lower values for net ME during forward (5.6%) and reverse (6.1%) wheelchair propulsion at 30 W. However,
these investigators have determined ME only at W between 15-30 W. The W, however, markedly affects ME (Van der Woude et al. 1988), which may in part explain the low values found by Linden et al. (1993). The result of the present study also confirmed the relationship between W and ME. Noteworthy is the low ME at 30 W, which was significantly lower during SACE compared to AACE and may be explained by the flywheel mass and the moment of inertia at this low W (Binkhorst and Vissers 1983). This seems to affect the motion during SACE more than during AACE. At a higher W the flywheel-mass effect is less and no differences were found in ME between SACE and AACE.

The physiological responses to maximal AACE found in this study are in agreement with previously reported values on able-bodied subjects (Sawka 1986; Hopman et al. 1992). It has been suggested that SACE may provide benefits in achieving higher W using the trunk as a fulcrum to generate force, whereas during AACE the trunk only has a function in stabilising the body. In addition, differences in physiological responses or maximal W may be expected based on substantial differences in the way the arm muscles are used during force delivery while rotating the flywheel asynchronously or synchronously and based on differences in the compensatory muscle activity of the legs and trunk between both types of ACE. This was confirmed by differences in EMG activity – an early onset of activity of the abdominal muscles during SACE and activity of the triceps muscles for about 75% of the cycle-time during SACE and only for 50% during AACE.

However, results of this study indicated that there were no differences in physiological responses and Wpeak between SACE and AACE for able-bodied subjects with normal use of leg, trunk and arm muscles. Additional research is needed to examine whether or not this holds true for wheelchair users, such as individuals with spinal cord injuries who can only use part of their trunk muscles and have no control over their leg muscles.

It is worth noting that subjectively (asked after finishing both tests) seven out of the ten subjects felt AACE to be easier than SACE, whereas only one subject felt SACE to be easier.

The differences between the first and second test cannot be explained by a learning effect of the first test, since all the subjects had participated in other studies and were used to ACE. In addition, ME did not change, which confirms in another way that the observed differences were not based on an improvement in skills. However, these results once more show the importance of a counterbalanced design for a study in which two or more tests are compared.

In conclusion, during maximal exercise the physiological responses were not significantly different between AACE and SACE. The ME did not appear to be different between the two types of exercise at higher W, however ME showed a decrease at lower W most likely due to a flywheel-mass effect, which was more pronounced during SACE than during AACE.

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References


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