

Commuter cycling: effect on physical performance in untrained men and women in Flanders: minimum dose to improve indexes of fitness

B. de Geus, J. Joncheere, R. Meeusen

Department of Human Physiology and Sports Medicine, Policy Research Centre Sport, Physical Activity and Health, Vrije Universiteit Brussel, Faculteit LK, Pleinlaan Brussels, Belgium

Corresponding author: Prof. Dr. Romain Meeusen, Department Human Physiology & Sports Medicine, Policy Research Centre Sport, Physical Activity and Health, Vrije Universiteit Brussel, Faculteit LK, Pleinlaan 2, B-1050 Brussels, Belgium. Tel: +32 2 6292222, Fax: +32 2 6292876, E-mail: rmeeusen@vub.ac.be

Accepted for publication 19 December 2007

The purpose was to examine (1) the effect of cycling to work on physical performance; (2) the minimum weekly energy expenditure needed for fitness improvement based on the dose–response relationship between total caloric expenditure and fitness changes. Healthy, untrained men and women, who did not cycle to work, participated in a 1-year intervention study. Sixty-five subjects were asked to cycle to work at least three times a week. Fifteen subjects were asked not to change their living habits. All measurements were performed on three consecutive occasions, with 6 months in between. Maximal external power (P_{\max}), heart

rate, respiratory exchange ratio and peak oxygen uptake ($\text{VO}_{2\text{peak}}$) were assessed. Cycling characteristics and leisure time physical activities were reported in a diary. A significant change over time between both groups was seen for $\text{VO}_{2\text{peak}}$ (/kg) in the total group and the women and for P_{\max} in the total group. Correlations were found between $\text{VO}_{2\text{peak}}$ (/kg) ($r \geq 0.40$) and kcal/week and min/week. Preliminary results indicate that the minimum expended energy needed for the improvement of indexes of fitness is higher for men compared with women.

Despite warning about the potentially negative health consequences of a sedentary lifestyle, a large proportion of adults in North America (Pate et al., 1995) and Europe (Steptoe et al., 1997; Lemaître, 2005) is physically inactive. However, physical inactivity is a modifiable risk factor for cardiovascular disease and a variety of other chronic diseases, including diabetes, cancer (colon and breast), obesity, hypertension, bone and joint diseases (osteoporosis and osteoarthritis) (Puett & Griffin, 1994; Surgeon General Report, 1996; Blair et al., 1996; ACSM Position Stand, 1998; Blair & Brodney, 1999) and mental health (Penedo & Dahn, 2005).

As a reaction to this public health burden, the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) issued recommendations for physical activity and public health, where was stated that “every adult should accumulate 30 min or more of moderate-intensity physical activity on most, preferably all, days of the week” (Pate et al., 1995). In order to gain positive effects on aerobic fitness, the ACSM Position Stand (1998) states that: “adults should exercise 3–5 days/week at 55/65–90% of the maximal heart rate (HR) for 20–60 min or accumulate the same

amount of exercise in several daily bouts for a minimum of 10 min.”

Physical activity at moderate intensity may be easier to begin with, and will be more likely to be continued regularly (Vuori et al., 1994; Andersen et al., 1999; Dunn et al., 1999). Therefore, health experts are broadening their conceptualization of physical activity from leisure-time activity to ‘a lifestyle or way of life that integrates physical activity into the daily routine’ (Council of Europe, 1995). One way of being physically active on a daily basis that can be integrated in the day life routine is cycling to work (Oja et al., 1998; Andersen et al., 1999; Dunn et al., 1999). Cycling as transportation was shown to be inversely associated with all-cause mortality in both men and women in all age groups (Andersen et al., 2000). So far, only two studies, conducted in Finland (Oja et al., 1991) and the Netherlands (Hendriksen et al., 2000), addressed the issue of the effect of cycling to work on the physical performance, none of which addressed the question of a dose–response between total volume and intensity of physical activity and indexes of fitness.

Therefore, the purpose of this intervention study was to examine: (1) the effect of cycling to work on physical performance; (2) the minimum weekly

Table 1. Descriptive characteristics of the subjects at baseline (T1)

Intervention group	Total group (<i>n</i> = 65)	Men (<i>n</i> = 30)	Women (<i>n</i> = 35)
Age (year)*	43 ± 5 (33–54)	43 ± 6 (33–54)	43 ± 3 (34–53)
Height (cm)	171 ± 8 (154–196)	177 ± 6 (167–196)	166 ± 5 (154–176)
Weight (kg)	76 ± 13 (49–109)	84 ± 10 (65–108)	69 ± 12 (49–109)
BMI (kg/m ²)	26 ± 4 (18–42)	27 ± 3 (20–35)	25 ± 4 (18–42)
Control group	(<i>n</i> = 15)	(<i>n</i> = 7)	(<i>n</i> = 8)
Age (year)	49 ± 7 (37–58)	50 ± 8 (37–58)	48 ± 6 (39–56)
Height (cm)	170 ± 8 (153–181)	176 ± 4 (170–181)	165 ± 6 (153–172)
Weight (kg)	72 ± 11 (54–95)	79 ± 11 (67–95)	66 ± 7 (54–76)
BMI (kg/m ²)	25 ± 3 (21–31)	26 ± 3 (23–31)	24 ± 2 (21–28)

Values are means ± SD, and range in parentheses.

BMI, body mass index, weight/height².

Significant difference from the control group. **P* < 0.01.

energy expenditure needed for fitness improvement based on the dose–response relationship between total caloric expenditure and fitness changes.

Materials and methods

Study design

Members of the “Liberale Mutualiteit van Oost-Vlaanderen,” a health insurance company, were contacted to participate in this 1-year intervention study. After a first telephone contact, the subjects who passed the eligibility criteria were invited to the laboratory, where they underwent a medical preparticipation screening (ACSM, 2005). If no medical contra-indication to exercise was found, a maximal exercise test (MT) was performed. All subjects completed MT at the start of the study (T1), after 6 months (25.8 ± 4.1 weeks) (T2), and after 1 year (52.4 ± 5.6 weeks) (T3). Baseline measurements (T1) were conducted between April and June 2004.

Before the start of the study all subjects read and signed an informed consent statement. The Vrije Universiteit Brussel Ethical Committee approved the study protocol.

Subjects

During a telephone contact, members of the health insurance company were asked about commuting habits and participation in physical activity. The inclusion criteria were (1) 30–65 years of age, and (2) had to commute by motorized transport and not by bicycle for the last 6 months before the study. Performing cycling as sport or recreational hobby and more than 3 h of physical activity in 1 week during the last 6 months before the start of the study were considered exclusion criteria.

One hundred and one subjects passed the inclusion- and exclusion criteria and were willing to participate in the study. These subjects were invited to the laboratory for a medical preparticipation screening. Two subjects were excluded after the medical preparticipation screening due to a history of cardiovascular disease. The 99 subjects that passed the medical preparticipation screening underwent a MT to determine their physical performance. After MT another seven were excluded from participation due to a $\text{VO}_{2\text{peak}}$ above the 50th percentile for age and sex (ACSM, 2005).

Ninety-two subjects were thus enrolled in the intervention study and divided in an intervention group (IG) or a control group (CG). Group allocation was performed using the

distance to work environment and travel frequency to work. Those who lived between 2 and 15 km from their workplace and travelled to work at least three times a week were enrolled in the IG (*n* = 74). Subjects from the CG (*n* = 18) lived less than 2 km; more than 15 km from their workplace; or had to travel to work less than three times a week. The subjects in the CG were asked to refrain from initiating an exercise program and maintain their current lifestyle. Gender specific “city bikes” of similar quality were provided for the IG. All subjects were asked to maintain their dietary habits.

Five subjects (4 IG; 1 CG) did not show up at T2 and another seven (4 IG; 3 CG) dropped out before T3. This resulted in a total of 12 (13%) dropouts. Eighty subjects completed the study design. No significant differences at baseline, for any of the measured parameters, were found between the 12 subjects that did not show up at T2 or T3 and the 80 subjects that participated in the final measurements (data not shown). Table 1 list the descriptive characteristics of the 80 subjects that fulfilled the 1-year intervention study and were included in the data analysis.

Diaries

All subjects completed a week diary throughout the whole study. Subjects of the IG reported cycling data (indicated as “Cycling”) and leisure-time physical activities (indicated as “LTPA”). A distance recorder (CicloMaster CM206, KW Hochschorner, Krailling, Germany) registered the distance and the time spend on each trip. The distance recorders were carefully calibrated to each person’s unique wheel circumference at the start of the study. Besides the cycling data subjects wrote down LTPA data-like swimming, tennis, etc. These activities had to be specified for duration and intensity. The CG only completed the section of the diary that inquired about the LTPA.

The mean cycling distance, time and bouts/week was calculated by respectively dividing the total distance, time and bouts/week by the total number of week’s participation in the study. The MET value of cycling was calculated according to the cycling speed, using the compendium of physical activities (Ainsworth et al., 2000). Because the values in the compendium are those of a person with a resting oxygen uptake (VO_2) of 3.5 mL/kg/min, the values were recalculated to the individual resting VO_2 , using the formula of Byrne et al. (2005). The energy expenditure (kcal) was calculated as follows: MET × body weight × time. The same procedure

was used to calculate the energy expenditure of the LTPA. The sum of the energy expenditure from cycling to work (cycling) and the energy expenditure from LTPA provided the total amount of expended energy (total).

Descriptive statistics of the diary data are given in Table 2.

MT

Maximal physical performance was determined by a maximal incremental exercise test on an electrically braked cycle ergometer (Excalibur Lode, Groningen, the Netherlands). The saddle and handlebars were repositioned to suit each subject.

After resting measurements were collected, the maximal exercise test began with an initial workload of 50 W for men and 40 W for women at a pedalling rate of 70–80 rates per minute. A ramp protocol was chosen with a workload increase of 15 and 10 W/min for men and women, respectively. The subjects were encouraged to exert themselves until volitional exhaustion. The decision to stop was based on signals of extreme fatigue and was confirmed by a HR that approximated the theoretical maximal HR (220-age) and/or a respiratory exchange ratio (RER) above 1.10. After reaching exhaustion, the subjects had to continue cycling (50 W for men and 40 W women) until the HR reached a rate below 120 beats/min, according to the ACSM guidelines (2005). The maximal external power (P_{\max}) was defined as the highest power output that could be reached during the maximal exercise test.

Oxygen uptake (VO_2) and carbon dioxide production (CO_2) were measured throughout the test using a portable cardiopulmonary indirect breath-by-breath calorimetry system (MetaMax[®] 3B, Cortex Biophysik, Leipzig, Germany). The validity of the MetaMax 3B was tested in an independent study (Wüpper et al., 2003). A flexible facemask (Cortex Adult Face Mask, Cortex Biophysik, Leipzig, Germany) covered the subject's mouth and nose. Before each test, gas and volume calibration took place with a 3-L syringe, according to the manufacturer's guidelines. The oxygen analyzer was calibrated with known gas mixtures of 18% O_2 and 5% CO_2 . The room air calibration was automatically run before each test to update the CO_2 analyzer baseline and the O_2 analyzer gain so that they coincided with atmospheric values. $\text{VO}_{2\text{peak}}$ was defined as the highest VO_2 attained during MT over a time interval of 30 s (de Geus et al., 2007). RER was calculated by dividing the measured CO_2 by the measured O_2 . HR was recorded through the MetaMax[®] via a Polar[®] X-Trainer Plus (Polar Electro OY, Kempele, Finland) measurement system. Maximal heart rate (HR_{\max}) was defined as the highest HR during the test. In order to measure the lactate concentration blood samples (20 μL) were drawn from an arterialized ear lobe, before the start of the maximal exercise test and at the point of exhaustion. Lactate concentrations were determined enzymatically (EKF, BIOSEN 5030, Magdeburg, Germany). Subjects were also requested to state their rate of perceived exertion according to Borg's scale (Borg, 1962) of six to 20 before and at the end of the test.

Statistical analysis

Data analysis was carried out using the Statistical Package for the Social Sciences (SPSS 13.0, Inc., Chicago, Illinois, USA).

The intention-to-treat principle was used, and all the study subjects were asked to participate in the three measurements (T1–T3), in spite of possible discontinuation from the exercise program (Asikainen et al., 2002), which consisted of cycling to work at least three times a week during 1 year.

The results are presented as means \pm SD. The one-sample Kolmogorov–Smirnov goodness of fit test was used to test whether the outcome variables had a normal distribution. Independent sample *t*-tests were performed to analyze differences between the IG and the CG at baseline. Two-way analysis of covariance (ANCOVA) with repeated measures on one factor (time) was used to test for a change over time between the IG and the CG for the indexes of fitness. Age was used as a covariate, because both groups significantly differed at baseline. If a significant change over time was found between both groups Bonferroni's post hoc tests were performed. The level of statistical significance was set at $P < 0.01$ to help protect against potential type I errors.

The associations between the most important physical parameters [P_{\max} (/kg) and $\text{VO}_{2\text{peak}}$ (/kg)] and the measures for total volume (kcal/week, min/week) were analyzed using Pearson's (*r*) correlation analysis. In order to find the minimum dose of weekly energy expenditure (kcal/week) needed to improve the maximal external power [P_{\max} (/kg)] and the peak oxygen uptake [$\text{VO}_{2\text{peak}}$ (/kg)], weekly energy expenditure data were grouped in tertiles for the total group, men and women separately. ANOVA analyses were performed in the total group, men and women separately to analyze the interaction of these factors with the physical parameters.

Results

For the total IG ($n = 65$), the compliance (cycling ≥ 3 times a week to work) was 38% during the first 6 months and 34% during the second 6 months, with men having a higher compliance.

Table 1 shows the results of the descriptive variables. Subjects of the IG (43 ± 5 years) were significantly younger than the CG (49 ± 7 years). Except for age, no differences in measured descriptive or physiological parameters at baseline were found between the IG and CG.

Cycling data

Table 2 shows the values for the IG of the cycling data (cycling) as written down in the diaries, for the total group, men and women. In comparison with the first period (T1–T2), the total group, men and women cycled significantly ($P < 0.01$) less bouts/week and spend significantly ($P < 0.01$) less energy (kcal/week) in the second period (T2–T3). The cycling intensity (MET) decreased significantly ($P < 0.01$) in the second period (T2–T3) in comparison with the first period (T1–T2) in the total IG group.

LTPA data

In the total IG and women IG, the bouts/week and min/week decreased significantly ($P < 0.01$) in the second period, in comparison with the first period.

Table 2. Cycling characteristics (cycling), leisure-time physical activity (LTPA) data and the sum of the cycling and LTPA data (total) for the intervention group and LTPA data for the control group in the first period (T1–T2), the second period (T2–T3) and the total period (T1–T3)

	Total group			Men			Women		
	T1–T2	T2–T3	T1–T3	T1–T2	T2–T3	T1–T3	T1–T2	T2–T3	T1–T3
<i>Intervention group</i>									
<i>Cycling</i>									
Km/week	40.6 ± 25.8	31.6 ± 27.8	35.0 ± 23.6	49.4 ± 28.9	40.2 ± 31.6	44.4 ± 27.1	33.1 ± 20.5	24.2 ± 21.8	27.1 ± 16.7
Km/h	18.1 ± 5.1	17.4 ± 6.6	18.3 ± 5.0	20.5 ± 6.0	19.5 ± 7.7	20.7 ± 5.9	16.1 ± 3.0	15.7 ± 4.9	16.3 ± 3.0
Bouts/week	2.9 ± 1.1	2.3 ± 1.6 [†]	2.5 ± 1.1	3.0 ± 1.0	2.4 ± 1.4 [†]	2.7 ± 1.0	2.9 ± 1.1	2.2 ± 1.7 [†]	2.4 ± 1.2
Min/week	132 ± 68	101 ± 81	112 ± 63	144 ± 73	115 ± 81	128 ± 69	121 ± 62	90 ± 80	99 ± 56
Kcal/week	1091 ± 894	718 ± 745 [†]	879 ± 741	1527 ± 1058	1055 ± 901 [†]	1272 ± 877	717 ± 488	429 ± 405 [†]	542 ± 355
MET	6.2 ± 2.4	5.5 ± 2.6 [†]	5.7 ± 2.2	7.3 ± 2.7	6.6 ± 3.1	6.8 ± 2.5	5.3 ± 1.7	4.5 ± 1.7	4.8 ± 1.4
<i>LTPA</i>									
Bouts/week	1.0 ± 0.7	0.7 ± 0.8 [†]	0.8 ± 0.7	0.9 ± 0.5	0.7 ± 0.7	0.8 ± 0.6	1.0 ± 0.7	0.6 ± 0.8 [†]	0.8 ± 0.7
Min/week	136 ± 117	90 ± 109 [†]	111 ± 98	146 ± 112	114 ± 116	124 ± 96	127 ± 122	70 ± 99 [†]	99 ± 100
Kcal/week	685 ± 549	500 ± 686	594 ± 570	862 ± 590	684 ± 821	762 ± 647	533 ± 468	342 ± 507	450 ± 457
MET	5.7 ± 0.9	5.6 ± 1.2	5.7 ± 0.9	5.8 ± 1.0	5.6 ± 1.2	5.7 ± 1.1	5.7 ± 0.7	5.6 ± 1.2	5.7 ± 0.8
<i>Total</i>									
Bouts/week	3.9 ± 1.3	3.0 ± 1.8 ^{†*}	3.4 ± 1.4	3.9 ± 1.3 [*]	3.1 ± 1.6 [†]	3.4 ± 1.2 [*]	3.9 ± 1.4	2.8 ± 2.0 [†]	3.3 ± 1.6
Min/week	267 ± 129 [*]	191 ± 137 [†]	223 ± 116 [*]	290 ± 118 [*]	228 ± 137 [*]	252 ± 112 [*]	248 ± 136	159 ± 131 [†]	198 ± 116
Kcal/week	1776 ± 1118 [*]	1218 ± 1072 ^{†*}	1473 ± 1014 [*]	2390 ± 1236 [*]	1739 ± 1215 ^{†*}	2033 ± 1120 [*]	1249 ± 656 [*]	770 ± 677 [†]	992 ± 592
MET	5.9 ± 1.3	5.4 ± 1.5 [†]	5.7 ± 1.2	6.5 ± 1.3	6.0 ± 1.6	6.3 ± 1.2	5.4 ± 1.0	4.9 ± 1.3	5.2 ± 0.8
<i>Control group</i>									
<i>LTPA</i>									
Bouts/week	0.9 ± 0.7	0.8 ± 0.7	0.9 ± 0.6	0.7 ± 0.3	0.5 ± 0.5	0.6 ± 0.3	1.1 ± 0.8	1.0 ± 0.8	1.1 ± 0.7
Min/week	117 ± 75	124 ± 123	102 ± 55	95 ± 71	79 ± 99	66 ± 40	137 ± 78	164 ± 134	134 ± 48
Kcal/week	578 ± 333	501 ± 429	531 ± 222	566 ± 370	348 ± 435	453 ± 186	588 ± 322	635 ± 402	599 ± 240
MET	5.5 ± 1.2	4.9 ± 0.8	5.2 ± 1.0	5.5 ± 1.3	4.7 ± 0.6	5.1 ± 1.0	5.5 ± 1.2	4.9 ± 0.9	5.3 ± 1.0

Values are means ± SD.

Significant difference from the first period (T1–T2): [†] $P < 0.01$.

Significant difference from the control group: ^{*} $P < 0.01$.

Total (cycling+LTPA)

Comparing the IG with the CG, shows that for the total group and men, min/week and kcal/week were significantly ($P < 0.01$) higher in the total, first and second period, although not statistically for the min/week in the second period in the total group. For women kcal/week was significantly ($P < 0.01$) higher in the IG, during the first period, comparing with women CG. All measures (min/week, bouts/week and kcal/week) decreased in the second period, in the total IG, men IG and women IG. The intensity (MET) decreased significant ($P < 0.01$) in the second period (T2–T3) in comparison with the first period (T1–T2) in the total IG group.

Physical performance data

The results of the measured physiological parameters for the IG and the CG are shown in Table 3. Table 4 shows the percentage change of the absolute and relative maximal external power and peak oxygen uptake.

At baseline, no statistical difference was found between the IG and the CG for the measured physiological parameters.

Significant ($P < 0.01$) changes over time between both groups were seen for the maximal external power [P_{\max} (/kg)] and peak oxygen uptake [$VO_{2\text{peak}}$ (/kg)], for the total group during the first period (T1–T2). During the total period (T1–T3), the absolute maximal external power (P_{\max}) and the relative peak oxygen uptake ($VO_{2\text{peak}}$ /kg) showed a significant ($P < 0.01$) change over time between both groups. The maximal external power [P_{\max} (/kg)] produced by subjects in the total IG at T2 and T3 was significantly ($P < 0.01$) higher than at baseline. The percentage change between T1 and T2 for P_{\max} (/kg) was respectively +6.5% and +7.0%. Between T2 and T3, the P_{\max} (/kg) decreased slightly (respectively –0.4% and –1.2%), although the values at T3 stayed significantly ($P < 0.01$) higher than at baseline (respectively +5.5% and +5.2%). In the CG, the $VO_{2\text{peak}}$ (/kg) decreased significantly ($P < 0.01$) between T1 and T2.

In men, no significant change over time was seen between both groups.

In women, the change over time of $VO_{2\text{peak}}$ (/kg) and RER was significant ($P < 0.01$) between groups for the total period (T1–T3). The P_{\max} (/kg) increased significantly ($P < 0.01$) in the first period with +7.7 and +7.8%, respectively. In the second period, the women were able to maintain their gain in

Table 3. Results of the three maximal exercise test (T1, T2, T3) for maximal external power [P_{\max} (W/kg)], peak oxygen uptake ($VO_{2\text{peak}}$ (L/min)), maximal heart rate (HR_{\max}), and maximal respiratory exchange ratio (RER_{\max})

Intervention group	Total group					
	Men			Women		
	T1	T2	T3	T1	T2	T3
P_{\max} (W)	203 ± 62	214 ± 62 [§]	213 ± 65 ^{†§}	258 ± 43	269 ± 40 [†]	267 ± 48
P_{\max} /kg (W/kg)	2.66 ± 0.63	2.82 ± 0.64 ^{†§}	2.79 ± 0.69 [†]	3.07 ± 0.50	3.24 ± 0.46 [†]	3.20 ± 0.61
$VO_{2\text{peak}}$ (L/min)	2.40 ± 0.64	2.42 ± 0.66 [§]	2.41 ± 0.74	2.98 ± 0.41	2.99 ± 0.45	3.01 ± 0.61
$VO_{2\text{peak}}$ /kg (mL/kg/min)	31.5 ± 6.0	31.9 ± 6.2 [§]	31.1 ± 7.5 [§]	35.8 ± 4.4	35.8 ± 4.6	35.6 ± 7.1
HR_{\max} (beats/min)	178 ± 14	178 ± 12	176 ± 14	175 ± 16	177 ± 14	176 ± 17
RER_{\max} ($VO_{2\text{peak}}/VO_{2\text{e}}$)	1.16 ± 0.08	1.19 ± 0.10 [†]	1.22 ± 0.09 [†]	1.15 ± 0.08	1.22 ± 0.10 [†]	1.22 ± 0.07 [†]
Control group						
P_{\max} (W)	191 ± 46	186 ± 45	192 ± 47	225 ± 45	219 ± 45	228 ± 41
P_{\max} /kg (W/kg)	2.63 ± 0.44	2.56 ± 0.43	2.68 ± 0.47	2.84 ± 0.56	2.75 ± 0.56	2.91 ± 0.51
$VO_{2\text{peak}}$ (L/min)	2.33 ± 0.54	2.14 ± 0.53 [†]	2.16 ± 0.47	2.79 ± 0.41	2.61 ± 0.33	2.62 ± 0.32
$VO_{2\text{peak}}$ /kg (mL/kg/min)	32.3 ± 5.5	29.4 ± 5.0 [†]	29.9 ± 4.6	35.6 ± 5.9	32.9 ± 4.2	32.2 ± 4.7 [†]
HR_{\max} (beats/min)	176 ± 11	175 ± 14	170 ± 13 [†]	177 ± 9	173 ± 14	169 ± 13 [†]
RER_{\max} ($VO_{2\text{peak}}/VO_{2\text{e}}$)	1.21 ± 0.08	1.25 ± 0.07	1.22 ± 0.10	1.23 ± 0.10	1.24 ± 0.06	1.24 ± 0.12

Values are means ± SD.

T1, test at baseline; T2, test after 6 months; T3, test after 12 months.

Significant change over time between intervention group and control group: [§] $P < 0.01$.

Significant difference from T1: [†] $P < 0.01$.

Table 4. Percentage change in maximal external power [P_{\max} (W/kg)] and peak oxygen uptake [$VO_{2\text{peak}}$ (L/min)]

Intervention group	Total group					
	Men			Women		
	T2-T1	T3-T2	T3-T1	T2-T1	T3-T2	T3-T1
P_{\max} (W)	+6.5 ± 11.4*	-0.4 ± 10.9 [†]	+5.5 ± 12.2	+5.1 ± 6.6*	-0.8 ± 10.8	+3.9 ± 11.0
P_{\max} /kg (W/kg)	+7.0 ± 12.0*	-1.2 ± 11.4 ^{†,§}	+5.2 ± 13.0	+6.1 ± 9.1	-1.2 ± 11.1	+4.5 ± 11.8
$VO_{2\text{peak}}$ (L/min)	+1.2 ± 10.3*	-1.7 ± 12.2 [§]	+0.2 ± 13.0	+0.4 ± 7.1	-1.1 ± 13.6	+0.9 ± 14.8
$VO_{2\text{peak}}$ /kg (mL/kg/min)	+1.6 ± 10.2*	-3.4 ± 12.4 ^{†,§}	-1.1 ± 12.9	+0.8 ± 8.2	-2.2 ± 14.0	-0.1 ± 13.4
Control group						
P_{\max} (Watt)	-2.1 ± 6.3	+3.2 ± 10.8	+0.8 ± 10.9	-2.6 ± 4.9	+5.2 ± 12.9	+2.4 ± 13.6
P_{\max} /kg (W/kg)	-2.4 ± 7.3	+5.0 ± 10.6	+2.3 ± 11.7	-3.4 ± 5.5	+7.0 ± 12.6	+3.4 ± 14.3
$VO_{2\text{peak}}$ (L/min)	-8.5 ± 9.5	+4.6 ± 14.6	-5.9 ± 9.8	-5.9 ± 6.4	+1.7 ± 10.1	-5.9 ± 10.1
$VO_{2\text{peak}}$ /kg (mL/kg/min)	-8.8 ± 10.1	+3.8 ± 10.9	-6.8 ± 9.8	-7.0 ± 7.5	-0.9 ± 6.6	-9.7 ± 5.5

Values are means ± SD.

T2-T1, first 6 months; T3-T2, second 6 months; T3-T1, 12 months.

Significant change over time between intervention group and control group: [§] $P < 0.01$

Significant difference from control group: * $P < 0.01$.

Significant difference from first period (T2-T1): [†] $P < 0.01$.

Table 5. Correlations (*r*) between the maximal external power [P_{\max} (/kg)] and peak oxygen uptake [$VO_{2\text{peak}}$ (/kg)] and the measures of volume (kcal/week, min/week) during the first period (T1–T2)

	Total group (<i>n</i> = 80)		Men (<i>n</i> = 37)		Women (<i>n</i> = 43)	
	kcal/week	min/week	kcal/week	min/week	kcal/week	min/week
P_{\max}	0.26	0.25	0.32	0.25	0.28	0.26
P_{\max}/kg	0.24	0.24	0.31	0.25	0.26	0.24
$VO_{2\text{peak}}$	0.42*	0.40*	0.53*	0.48*	0.44*	0.34
$VO_{2\text{peak}}/\text{kg}$	0.36*	0.33*	0.47*	0.38	0.39*	0.29

Significant correlation: * $P < 0.01$.

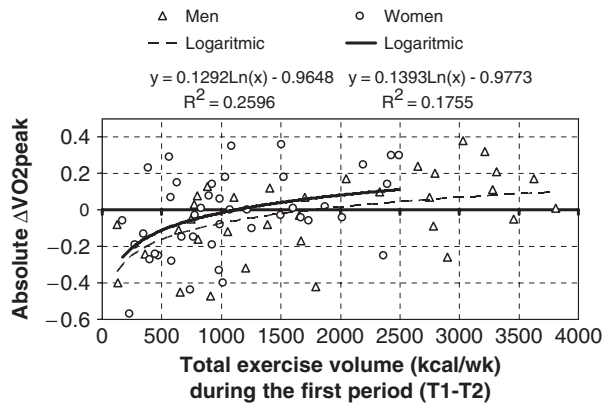


Fig. 1. Change in absolute peak oxygen uptake ($\bullet VO_{2\text{peak}}$) as a function of total exercise volume (kcal/week) during the first period (T1–T2) of the study.

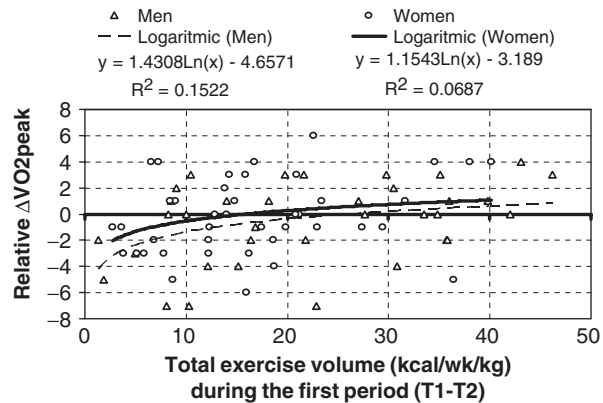


Fig. 2. Change in relative peak oxygen uptake ($\bullet VO_{2\text{peak}}/\text{kg}$) as a function of total exercise volume (kcal/week/kg) during the first period (T1–T2) of the study.

P_{\max} , with significantly ($P < 0.01$) higher values than at T1.

Dose–response

Table 5 gives the Pearson’s (*r*) correlations between the physiological parameters [P_{\max} (/kg) and $VO_{2\text{peak}}$ (/kg)] and the measures for total volume (kcal/week and min/week). Only the correlations from the first

Table 6. Total kcal/week shown per tertiles for the first period (T1–T2). The change in peak oxygen uptake ($VO_{2\text{peak}}$) was significantly different between the first and the third tertile. For the total group, there was also a significant difference between the first and the second tertile

	Tertile 1	Tertile 2	Tertile 3
Total group [§]	< 870	870–1720*	> 1720*
Men [§]	< 1080	1080–2780	> 2780*
Women [§]	< 750	750–1260	> 1260*

Significant difference (ANOVA).

[§] $P < 0.01$

Significant difference with tertile 1.

* $P < 0.01$.

period (T1–T2) are shown, because no significant correlations were found in the second period (T2–T3) or the whole study (T1–T3). Weak, but significant ($P < 0.01$) correlations were found between the peak oxygen uptake [$VO_{2\text{peak}}$ (/kg)] and total volume for the total group ($r = 0.40$), men ($r = 0.50$) and women ($r = 0.40$) separately.

Figures 1 and 2 shows the change in peak oxygen uptake [$VO_{2\text{peak}}$ (/kg)] as a function of total energy expenditure [kcal/week (/kg)] during the first period (T1–T2) of the study and indicate that the gain in $VO_{2\text{peak}}$ becomes positive when expending approximately 1000 and 1500/kcal/week for women and men, respectively. Analyses of variance (ANOVA) for the peak oxygen uptake ($VO_{2\text{peak}}$) by kcal/week tertiles showed significant ($P < 0.01$) differences for the total group, men and women separately (Table 6). *Post hoc* tests revealed that the change in peak oxygen uptake between T1 and T2 in subjects in the lowest kcal/week tertile was significantly ($P < 0.01$) lower than those in the highest tertile. This was true for the total group, men and women separately. For men, the change in $VO_{2\text{peak}}$ was significantly lower in those who expended less than 1080 kcal/week in comparison with those who expended more than 2780 kcal/week. The same was true for women with those who expended < 750 kcal/week in comparison with those who expended more than 1260 kcal/week.

Discussion

The aim of this 1-year intervention study was to examine whether cycling to work has a positive influence on the physical performance. Furthermore, we investigated whether there is a minimum energy expenditure needed to increase indexes of fitness in untrained but healthy men and women. The main results indicate that cycling to work at a self-paced intensity has a positive influence on indexes of fitness. There seems to be a significant, although weak correlation between the total-expended energy and the peak oxygen uptake.

To our knowledge, only two studies investigated the effect of commuter cycling on the physical performance. In the study of Hendriksen et al. (2000), conducted in the Netherlands, subjects had to cycle to work at least three times a week for 1 year. In the study of Oja et al. (1991) subjects cycled to work for 10 weeks. The difference with the previous studies is that it is the first time that a commuter cycling study is conducted in Flanders (Belgium) and the first time that cycling and LTPA characteristics are written down in diaries during the 1-year duration of the study.

Indexes of fitness

In order to gain positive effects on aerobic fitness adults should exercise 3–5 days/week at 55/65–90% of the maximal HR for 20–60 min or accumulate the same amount of exercise in several daily bouts (ACSM, 1998). In our study subjects in the IG exercised on average 250 min/week at a mean frequency of 3.9 bouts/week (cycling+LTPA). Previously, it was shown that cycling to work was done at an intensity of >75% of the maximal performance in previously untrained middle-aged adults (de Geus et al., 2007).

The P_{\max} (/kg) increased significantly in the first period and remained unchanged or went back to baseline values in the second period in the IG. The results in our study are comparable with the results of Hendriksen et al. (2000), where the P_{\max} /kg increased with almost 13% in men and women in the first 6 months. The $VO_{2\text{peak}}$ (/kg) seems only slightly influenced by cycling to work. In the first period of our study, the $VO_{2\text{peak}}$ /kg increased with 1.6% (total group), 0.8% (men) and 2.2% (women). In the study of Hendriksen et al. (2000) the $VO_{2\text{max}}$ /kg increased with 6.1% in men and decreased 2.2% in women after 6 months. In the study of Oja et al. (1991) the $VO_{2\text{max}}$ /kg increased 3.4% after 10 weeks of commuter cycling. The men and women in the study of Hendriksen et al. (2000) cycled more bouts/week, over a longer one-way distance and so they cycled a higher amount of kilometers during the first 6 months, than the subjects in our

study. At the third maximal exercise test (T3), the indexes of fitness in the IG decreased in men and women, in comparison with T2, although they stayed above the baseline values. In the study of Hendriksen et al. (2000) the P_{\max} /kg only increased with 0.6% and 3.0% in men and women respectively in the second 6 months period. The $VO_{2\text{max}}$ /kg decreased in men (1.3%) and increased in women (1.4%). The rather limited increase or even decrease in indexes of fitness in the second part of our study could be due to the fact that total volume of physical activity (kcal/week and min/week), bouts/week and total cycled kilometers decreased. This was also the case in the study of Hendriksen et al. (2000) where the cycled distance decreased from 1524 km in the first 6 months to 893 km in the second 6 months. No data were available on the bouts/week of cycling during the second 6 months. Another element could be that individuals should be encouraged to increase their volume and/or intensity of exercise as their fitness level improves during the training program (ACSM, 1998).

Dose–response

The ACSM (1998) views exercise/physical activity for health and fitness in the context of an exercise dose continuum. That is, there is a dose–response to exercise by which benefits are derived through varying quantities of physical activity ranging from approximately 700–2000 plus kcal of effort per week (ACSM, 1998). This approximation was made starting from other studies, were 150 kcal/day (Surgeon General Report, 1996; Lee & Skerrett, 2001) to 200 kcal/day (Pate et al., 1995) was advocated to be associated with substantial health benefits.

The power of the CDC & ACSM (Pate et al., 1995) and ACSM (1998) recommendations is weakened by a large overlap in membership among various expert groups (Shephard, 2001) and the fact that many of these issues are based as much on concept and assumption as on well-established scientific fact (Surgeon General Report, 1996). Therefore, it was suggested that further research is required to refine them (Surgeon General Report, 1996). The first question that rises is if a specification should be made based on gender, since men and women will expend different amounts of energy when performing the same activity during the same time period (de Geus et al., 2007).

In the first period of our study, the mean energy expenditure of the total group was 1780 kcal/week and the increase in P_{\max} /kg and $VO_{2\text{peak}}$ /kg was 7.0% and 1.6%, respectively. In men, the increase in P_{\max} /kg was 6.1% and the increase in $VO_{2\text{peak}}$ /kg was 0.8%, with an energy expenditure of 2400 kcal/week in the first period. Women on the other hand expended half the energy (1250 kcal/week) in nearly

the same amount of time (248 vs 290 min/week) and their increase in P_{\max} /kg was 7.8% and $VO_{2\text{peak}}$ /kg 2.2%.

In his review on the dose–response between total volume of physical activity, health and fitness, Oja (2001) stated that no studies were identified that specifically addresses the volume–outcome dose–response. More recently, it was shown in a randomized-controlled trial (Asikainen et al., 2002) that walking 24 weeks at moderate intensity (45–55% $VO_{2\text{max}}$), with a total weekly energy expenditure of 1000–1500 kcal/week improved $VO_{2\text{max}}$ of previously sedentary, non-obese postmenopausal women. The 1000 kcal/week seemed to approach, but not reach the minimum dose, as even the lowest dose of walking improved maximal aerobic power (Asikainen et al., 2002). In our study, the change in peak oxygen uptake was significantly less in men expending up to 1080 kcal/week and women expending up to 750 kcal/week in comparison with men and women expending 2780 and 1260 kcal/week, respectively. Results from Table 5 show that weak but significant correlations exists between the peak oxygen uptake [$VO_{2\text{peak}}$ (/kg)] and total expended energy [kcal/week(/kg)] for the total group, men and women separately, indicating that the more one exercises the bigger the gain in oxygen uptake. Figures 1 and 2 indicate that the gain in $VO_{2\text{peak}}$ becomes positive when expending approximately 1000 and 1500 kcal/week for women and men, respectively.

The baseline tests (T1) were conducted between April and June, which makes that the second series of tests (T2) were conducted in the autumn and the beginning of the winter (October–December). This period of the year is characterised by rain and cold weather and seasonal changes in mood and behavior, a phenomenon also experienced across the healthy population (Mersch et al., 1999). The season could have had an impact on the results of the maximal exercise test, especially in the CG. The subjects cycled fewer kilometers and fewer bouts a week during the second period (T2–T3) in comparison with the first period (Table 2). This could also have resulted from a seasonal effect since T2–T3 took place in the second part of the autumn and the winter, a period when cycling is less pleasant.

Accessory we cannot exclude that the decrease during T2–T3 is caused by a decrease in motivation of the subjects.

Concluding we can state that, based on the results of this study, cycling to work has the potential to increase physical performance in an untrained study population. The maximal external power and peak oxygen uptake significantly changed over time when the IG and CG were compared. Weak, but significant correlations were found between the peak oxygen uptake and total volume in the first period.

Study limitations

Three study limitations should be recognized the most notable of which is the non-randomization of the sample. This could have induced a bias. All baseline physiological and psychological comparisons between the IG and CG suggest no significant differences. The one difference between the two groups is the different age, which was therefore included as a covariate in the statistics.

A second limitation is the rather limited number of subjects in the CG in comparison with the IG. A consequence of the limited number of subjects in the CG is a reduction of the validity of the results.

A third problem with the present and similar investigations is the potential error associated with the daily diaries. Sedentary adults tend to overestimate the intensity of their activity, specifically for moderate activity (Duncan et al., 2001), which could as a consequence have induced an overestimation of the expended energy.

The MET values in the compendium of Ainsworth et al. (2000) were individualized by using the calculated RMR. By this procedure we might induce a possible systematic error in the calculation of the energy expenditure as multiples of the true RMR.

Strengths

Several aspects of the present study represent significant strengths.

The long and well documented intervention study provides important new information on the potential of lifestyle physical activity to benefit physiological function, and eventually health. The study group is sufficiently large and the compliance to the intervention is good.

Perspectives

Every adult should be physically active, preferably all days of the week, for at least 30 min (Pate et al., 1995). This physical activity should be integrated in the daily life routine because it will be more likely to be continued regularly (Oja et al., 1998; Andersen et al., 1999; Dunn et al., 1999). Cycling to work has been advocated as a promising way of increasing the total daily amount of physical activity (Oja et al., 1998; Hendriksen et al., 2000).

The results showed that 1 year of cycling to and from work, at a frequency and duration recommended by the ACSM (1998), in an unsupervised intervention study, improves physical performance in previously untrained middle-aged men and women. Exercise can be divided into two daily bouts without compromising the training effects. Preliminary results indicate that the minimum expended energy

needed for the improvement of indexes of fitness is higher for men compared with women.

Key words: cycling to work, dose–response, physical performance, physical activity, unsupervised, intervention, health.

References

- Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr, Schmitz KH, Emplincourt PO, Jacobs DR Jr, Leon AS. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000; 32(Suppl.): S498–S504.
- American College of Sports Medicine (ACSM). Guidelines for exercise testing and prescription, 7th edn. Philadelphia: Lippincott Williams & Wilkins, 2005, ISBN 0-7817-4506-3.
- American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 1998; 30(6): 975–991.
- Andersen LB, Schnohr P, Schroll M, Hein HO. All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. *Arch Intern Med* 2000; 160(11): 1621–1628.
- Andersen RE, Wadden TA, Bartlett SJ, Zemel B, Verde TJ, Franckowlak SF. Effects of lifestyle activity vs structured aerobic exercise in obese women. *JAMA* 1999; 281: 335–340.
- Asikainen T-M, Miilunpalo S, Oja P, Rinne M, Pasanen M, Uusi-Rasi K, Vuori I. Randomised, controlled walking trials in postmenopausal women: the minimum dose to improve aerobic fitness? *Br J Sports Med* 2002; 36: 189–194.
- Blair SN, Brodney S. Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues. *Med Sci Sports Exerc* 1999; 31: S646–S662.
- Blair SN, Kampert JB, Kohl HW III, Barlow CE, Macera CA, Paffenbarger RS Jr, Gibbons LW. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *JAMA* 1996; 276(3): 205–210.
- Borg G. The reliability and validity of a physical work test. *Acta Physiol Scand* 1962; 55: 33–36.
- Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005; 99: 1112–1119.
- Council of Europe. Recommendation NO R(95) 17 of the Committee of Ministers to the Member States on the significance of Sport for Society, Council of Europe, Strasbourg. CDDS 1995; 58(95): 8–10.
- Duncan GE, Sydenman SY, Perri MG, Limacher MC, Martin DA. Can adults recall the intensity of their physical activity? *Prev Med* 2001; 33: 18–26.
- Dunn AL, Marcus BH, Kampert JB, Garcia ME, Kohl HW, Blair SN. Comparison of lifestyle and structured interventions to increase physical activity and cardiorespiratory fitness. A randomised trial. *JAMA* 1999; 281: 327–334.
- de Geus B, De Smet S, Nijs J, Meeusen R. Determining the intensity and energy expenditure during commuter cycling. Cycling to work in a rural area. *Br J Sport Med* 2007; 41(1): 8–12.
- Hendriksen IJM, Zuiderveld B, Kemper HCG, Bezemer PD. Effect of commuter cycling on physical performance of male and female employees. *Med Sci Sports Exerc* 2000; 32: 504–510.
- Lee IM, Skerrett PJ. Physical activity and all-cause mortality: what is the dose-response relation? *Med Sci Sports Exerc* 2001; 33(6): S459–S471.
- Lemaître J. Sport. In: VRIND, Administratie Planning en Statistiek, Departement Algemene Zaken en Financiën, Ministerie van de Vlaamse gemeenschap 2005(D/2005/3241/096, ISBN 90-403-0225-1, NUR 781, pp 241) Brussels, Belgium
- Mersch PPA, Middeltorp HM, Bouhuys AL, Beersma DGM, Van den Hoofdakker RH. The prevalence of seasonal affective disorder in the Netherlands: a prospective and retrospective study of seasonal mood variation in the general population. *Biol Psychiatr* 1999; 45: 1013–1022.
- Oja P. Dose–response between total volume of physical activity and health and fitness. *Med Sci Sports Exerc* 2001; 33: S428–S437.
- Oja P, Mänttari A, Heinonen A, Kukkonen-Harjula K, Laukkanen R, Pasanen M, Vuori I. Physiological effects of walking and cycling to work. *Scan J Med Sci Sports* 1991; 1: 151–157.
- Oja P, Vuori I, Paronen O. Daily walking and cycling to work: their utility as health-enhancing physical activity. *Patient Educ Couns* 1998; 33(1 Suppl.): S87–S94.
- Pate RR, Pratt M, Blair SN. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995; 273(5): 402–407.
- Penedo FJ, Dahn JR. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Curr Opin Psychiatr* 2005; 18: 189–193.
- Puett DW, Griffin MR. Published trials of nonmedical and noninvasive therapies for hip and knee osteoarthritis. *Ann Intern Med* 1994; 121: 33–40.
- Shephard RJ. Absolute versus relative intensity of physical activity in a dose–response context. *Med Sci Sports Exerc* 2001; 33(6): S400–S418.
- Steptoe A, Wardle J, Fuller R, Holte A, Justo J, Sanderman R, Wichstrom L. Leisure-time physical exercise: prevalence, attitudinal correlates, and behavioural correlates among young Europeans from 21 countries. *Prev Med* 1997; 26: 845–854.
- U.S. Department of Health and Human Services. Physical activity and health: a report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Centre for Chronic Disease Prevention and Health Promotion, 1996.
- Vuori IM, Oja P, Paronen O. Physically active commuting to work—testing its potential for exercise promotion. *Med Sci Sports Exerc* 1994; 26(7): 844–850.
- Wüpper C, Hillmer-Vogel U, Niklas A. Validität der Einzelatembzugesanalyse—Ein Vergleich ewischen Metamax 3B (Fysieke activiteit. Cortex) und des Douglas-Bag-Methode. *Deutsche Zeitschrift für Sportmedizin* 2003; 54(7/8): S66.

Acknowledgements

This study is funded by the Flemish Government. Policy Research Centre Sport, Physical Activity and Health.

The authors would like to thank Jo Nijs for critical review of the manuscript.

The authors wish to acknowledge the Liberale Mutualiteit van Oost-Vlaanderen for their assistance in subject recruitment.