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Computer Program for Calculation of Oxygen Uptake

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Computer Program for Calculation of Oxygen Uptake

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GENERAL PROGRAM DESCRIPTION

This program, written in Super Basic, can be used to calculate O₂ uptake and CO₂ production in resting and exercising human test subjects. The set of data from which these calculations are made is entered into the program; included are measurements of O₂ and CO₂ in inspired air and expired respiratory gas, and various gas volumes, temperature, and pressure measurements. A flow diagram of the program is presented in Fig. 1.

The program will accommodate readings from two types of O₂ and CO₂ analyzers: indirect readout analyzers (Steps 10.1 and 12.1) which require the use of calibration curves to convert numerical readings of O₂ and CO₂ concentrations into percent, and direct readout analyzers (Steps 10, 11, 12, 13) which read directly in percent. For the indirect readout analyzers, the slopes and intercepts of the calibration curves must be entered as constants (Steps 2, 3, 4).

The program begins with a prompt (Step 5) that allows the operator to either print a set of instructions for running the program, or to go directly to the data input section of the program. The data can be entered "conversationally" through a series of prompts (Steps 6, 6.1, and 6.2), or they can be entered all at once, according to a specified format, without interruption (Steps 7, 8). Expired water vapor pressure is calculated in either Step 6.2A or 8.1, depending on which option for data input is selected.

Direct or indirect measurements of the concentrations of inspired CO₂ and O₂ can be entered in the program (Steps 14-19, excluding 14.1), to be used later in the ventilation calculations. However, if they are not measured, constant values for inspired CO₂ and O₂ concentrations can be used; 0.03% and 20.93%, respectively, are commonly used. These values have been incorporated into the program.
The major ventilation measurements in the O_2 uptake equation are printed out in Step 20; oxygen uptake, expressed in ml/kg/min, is printed in Step 22.2. The basic equations used to calculate these ventilation measurements were taken from Consolazio et al. (1).

A "no" input in response to the query "are you finished?" (Step 23) recycles the program to Step 6 for the next set of input data. One run through the program without use of the conversational queries takes less than 2 min. Run-time with the conversational queries requires less than 3 min. The run-time is partly dependent on the speed of the printer.

PROGRAM PRINTOUT AND EQUATIONS

The complete program is presented in Fig. 2; the statement numbers, description, and symbols for each function are given in Fig. 3. The basic equations used are as follows (1):

Water vapor pressure (P8) = P7/10^{Z_8} (760) (Ref. 2) (Step 6.2A or 8.1)

where: $Z_8 = \left( \frac{X_8}{T_8} \right) \left[ \frac{A_7+(B_7\cdot X_8)+(C_7\cdot X_8^3)}{1+(D_7\cdot X_8)} \right]

Expired O_2(Z) = B_2+(M_2\cdot F) (Step 10.2)
Expired CO_2(Y) = B_1+(M_1\cdot C) (Step 12.2)
Inspired CO_2 (H) = B+(M\cdot H_1) (Step 16.1)
Inspired O_2 (J) = B_2+(M_2\cdot J_1) (Step 17.2)
$\dot{V}_{EATPS}$ (W) = [(V_2-V_1)/T] (V_3) (Step 20)
STPD FACTOR (U) = (P-P_8)/760(1+0.00367G) (Step 20)
$\dot{V}_{ESTPD}$ (V) = W-U (Step 20)
$\dot{V}_{EBTPS}$ (O_3) = [W-(R_5\cdot D_5)] \left( \frac{P-P_8}{P-49.7} \right) \left( \frac{273+38}{273+G} \right) (Step 20)

where: 49.7 = H_2O vapor tension in expired air at $T_b$ of 38°C.
The printout of a sample calculation is presented in Fig. 4.

A comparison was made between 22 measurements of oxygen uptake, that ranged from 1.79 to 4.50 l/min, calculated from the nomogram of Consolazio et al. (1) and from the computer program (Fig. 5). The mean (±SD) of the nomogram values was 3.44 ±0.89 l/min versus 3.42 ±0.88 for the program data. The correlation coefficient was 1.00.

REFERENCES


FIG. 1. Flow diagram of program.
THIS PROGRAM CALCULATES OXYGEN CONSUMPTION

PRINT
AS="NO"
8-0.0040 87 INTERCEPT FOR INSPIRED CO2 CURVE. SEE STATEMENT 830"
W=0.0085 467 SLOPE FOR INSPIRED CO2 CURVE.
13 !
B1-0.01066 INTERCEPT FOR EXPIRED CO2 CURVE. SEE STATEMENT 670
M=0.03494 SLOPE FOR EXPIRED CO2 CURVE.
16 !
B2-0.002167 INTERCEPT FOR INSPIRED AND EXPIRED O2 CURVE
M1=0.03494 SLOPE FOR INSPIRED AND EXPIRED O2 CURVE
PRINT "DO YOU NEED INSTRUCTIONS? TYPE YES OR NO: ".
INPUT IN IMAGE ":I$"
30 IF I$="A9 THEN 100 ELSE 35
35 PRINT
40 PRINT "THIS PROGRAM CALCULATES OXYGEN CONSUMPTION. IT CAN BE USED""41 PRINT "WHEN EITHER OF TWO TYPES OF O2/CO2 ANALYZERS ARE AVAILABLE."
42 PRINT "THEY ARE: 1) DIRECT READOUT ANALYZERS (READINGS IN PERCENT OF""43 PRINT "GAS COMPOSITION), AND 2) INDIRECT READOUT ANALYZERS (WHICH""44 PRINT "REQUIRE USE OF A CALIBRATION CURVE)."
45 PRINT "THE SLOPES AND INTERCEP'TS OF THE CALIBRATION CURVES MUST BE"
46 PRINT "ENTERED INTO THIS PROGRAM AT STATEMENT NUMBERS 11 TO 18.""
47 PRINT
50 PRINT "WHEN REQUESTED TO TYPE (NO), DO NOT TYPE THE ENCLOSING ( )"
52 PRINT
60 PRINT "WHEN REQUIRED TO TYPE (NO), DO NOT TYPE THE ENCLOSING ()"
62 PRINT
64 PRINT "TO INTERRUPT THE EXECUTION OF THIS PROGRAM AT ANY POINT,"
66 PRINT "DEPRESS THE ALT MODE/ESCAPE KEY SEVERAL TIMES."
70 PRINT "THE PRIMARY EQUATIONS USED IN THIS PROGRAM PLUS THEIR""71 PRINT "ASSOCIATED MMEMONICS CAN BE FOUND IN STATEMENTS 580,""72 PRINT "1000 THROUGH 1090, AND 1325."
75 PRINT
80 PRINT "DATA CAN BE ENTERED IN TWO WAYS: 1) CONVERSATIONALLY AS A"
81 PRINT "STRING OF VARIABLES IN A SPECIFIED FORMAT, OR 2) CONVERS-
82 PRINT "ATIONALLY, IN RESPONSE TO COMPUTER-GENERATED QUESTIONS."
83 PRINT "CONVERSATIONAL? YES OR NO? GIVES YOU THE CHOICE OF HOW YOU"
84 PRINT "WANT TO INPUT THE DATA."
85 PRINT
100 PRINT
120 PRINT "CONVERSATIONAL? TYPE YES OR NO: ".
122 INPUT IN IMAGE "":C$"
123 PRINT
124 IF C$="A9 THEN 126 ELSE 200
126 PRINT "DO YOU NEED THE INPUT FORMAT? TYPE YES OR NO: ".
127 INPUT IN IMAGE "":F$"
128 IF F$="A9 THEN 158 ELSE 129
125 PRINT
130 PRINT "INSTRUCTIONS FOR ENTERING DATA ARE:""
131 PRINT
132 PRINT 1) SEPARATE EACH VARIABLE WITH A COMMA"
133 PRINT 2) PUSH THE LINE FEED KEY IF THE RIGHT-HAND EDGE OF THE""134 PRINT PAPER IS REACHED BEFORE ALL VARIABLES ARE ENTERED"
135 PRINT 3) TYPE (NO) IF BODY WT., ERGOMETER LOAD, OR TREADMILL"
136 PRINT SPEED ARE NOT MEASURED."
138 PRINT
139 PRINT "THE FORMAT FOR ENTERING DATA IS AS FOLLOWS:""
140 PRINT
141 PRINT 1) COLUMN 1 COLUMN 2"
143 PRINT D = DATE (ENCLOSE IN QUOTES) V1 = VOL. METER READ. INITIAL (L)"
144 PRINT SS = SUBJECT'S NAME VS = VOL. METER CORRECTION"
145 PRINT MS = BODY WT. (KG) KS = RESP. VALVE DEAD SPACE (L)"
146 PRINT ES = ERGOMETER LOAD (WATTS) G = GAS TEMPERATURE (CELSIUS)"
148 PRINT TS = TREADMILL SPEED (MPH) P = BAROMETRIC PRESS. (MM HG)"
150 PRINT SS = TIME, GAS COLLECT. (SEC) RS = RESPIRATORY RATE (BR/MM)"
154 PRINT TV = VOL. METER READ. FINAL (L)"
156 PRINT
160 PRINT "ENTER THE COLUMN 1 VARIABLES FIRST"
162 INPUT D,SS,WS,ES,TS,V1,V3,DS,G,PR"
166 PRINT
170 PRINT "DATE =":D
171 PRINT
172 PRINT "SUBJECT =":S$
173 PRINT
174 PRINT "BODY WEIGHT (KG) WS = "WS
175 PRINT "ERGOMETER LOAD (WATTS) ES = "ES
176 PRINT "TREADMILL SPEED (MPH) TS = "TS
177 PRINT
178 PRINT "TIME, GAS COLLECTION (SECONDS) S =":S;"SECONDS"
179 PRINT "RESP. GAS METER READING, FINAL V2 =":V2;"LITERS"
180 PRINT "RESP. GAS METER READING, INITIAL V1 =":V1;"LITERS"
181 PRINT "RESP. GAS METER CORRECTION V3 =":V3;"LITERS"
182 PRINT "RESP. VALVE DEAD SPACE DS =":DS;"LITERS"
183 PRINT "GAS TEMPERATURE G =":G;"CELSIUS"
184 PRINT "BAROMETRIC PRESSURE P =":P;"MM HG"
185 PRINT "RESPIRATORY RATE R$ =":R$;"BR/MIN"
186 PRINT "RESPIRATION RATE R$ =":R$;"BR/MIN"
187 GO TO 500
200 PRINT "DATE (FORMAT = MONTH DAY, YEAR) :");
210 INPUT IN IMAGE "#":D
215 PRINT
220 PRINT "SUBJECT'S NAME : ");
230 INPUT IN IMAGE "#":S$
250 PRINT
260 PRINT "BODY WT. (KG) (TYPE (NO) IF NOT MEASURED) WS = ":
270 INPUT IN IMAGE "#":WS
280 PRINT "ERGOMETER LOAD, (WATTS) (TYPE (NO) IF NOT MEASURED) : "
290 INPUT IN IMAGE "#":ES
300 PRINT "TREADMILL SPEED, (MPH) (TYPE (NO) IF NOT MEASURED) : "
310 INPUT IN IMAGE "#":TS
320 PRINT
330 PRINT "TIME, GAS COLLECTION (SEC.) S = ");
340 INPUT IN IMAGE "#":S$
350 PRINT "RESP. GAS METER READ., FINAL (LITERS) V2 = ");
360 INPUT IN IMAGE "#":V2
370 PRINT "RESP. GAS METER READ., INITIAL (LITERS) V1 = ");
380 INPUT IN IMAGE "#":V1
390 PRINT "RESP. GAS METER CORRECTION V3 = ");
400 INPUT IN IMAGE "#":V3
410 PRINT "RESP. VALVE DEAD SPACE DS = ");
420 INPUT IN IMAGE "#":DS
430 PRINT "GAS TEMPERATURE (CELSIUS) G = ");
440 INPUT IN IMAGE "#":G
450 PRINT "BAROMETRIC PRESSURE (MM HG) P = ");
460 INPUT IN IMAGE "#":P
470 PRINT "RESPIRATORY RATE (BR/MIN) R$ = ");
490 INPUT IN IMAGE "#":R$}
500 A7 = 3.2437814
510 B7 = 5.86826E-03
520 C7 = 1.1702379E-08
530 D7 = 2.1878462E-03
540 P1 = 218.167
550 TH = G + 273.16
560 X8 = 647.27 - T8
570 Z8 = (X8/T8)*((A7 + B7*X8 + C7*X8^2)/(1 + D7*X8))
580 P8 = (P7/10 + 28) * 760  ! P8 = PH20 SATURATED AT DBT
600 PRINT "WATER VAPOR PRESSURE P8 =":P8;" MM HG"
605 PRINT
630 PRINT "EXPRIED CO2, AS %, FROM DIRECT READOUT ANALYZER"
631 PRINT " (TYPE (NO) IF NOT MEASURED) FC02 = ");
650 INPUT IN IMAGE "#":Y
660 IF Y = 9 THEN 6/0 ELSE 690
670 PRINT "EXPRIED CO2 (READING FROM INDIRECT READOUT ANALYZER) C = ");
680 INPUT IN IMAGE "#":C
690 X = B7*(M - L)  ! FC02 [L]
690 PRINT "EXPRIED O2, AS %, FROM DIRECT READOUT ANALYZER"
691 PRINT " (TYPE (NO) IF NOT MEASURED) FO2 = ");

Fig. 2.- Continued

6
700 INPUT IN IMAGE "I"; Z
701 IF Z=A9 THEN 720 ELSE 745
720 PRINT "EXPIRED O2 (READING FROM INDIRECT READOUT ANALYZER) F= ";
730 INPUT IN IMAGE "F"; F
740 Z=F-Z+(M2*F) IF02 (%)
745 PRINT
750 PRINT "WERE INSPIRED CO2 AND O2 MEASURED? TYPE YES OR NO: ";
755 INPUT IN IMAGE "N"; N
757 PRINT
760 IF N=A9 THEN 770 ELSE 800
770 H=0.03
780 J=20.93
795 GO TO 919
800 PRINT "INSPIRED CO2, AS %, FROM DIRECT READOUT ANALYZER"
810 PRINT "TYPE (NO) IF NOT MEASURED) H= ";
820 INPUT IN IMAGE "H"; H
830 PRINT "INSPIRED O2 (READING FROM INDIRECT READOUT ANALYZER) J= ";
840 INPUT IN IMAGE "J"; J
850 IF H=0.03 THEN 860 ELSE 890
860 PRINT "INSPIRED CO2, AS %, FROM DIRECT READOUT ANALYZER"
861 PRINT "TYPE (NO) IF NOT MEASURED) J= ";
870 INPUT IN IMAGE "J"; J
880 IF J=A9 THEN 890 ELSE 918
890 PRINT "INSPIRED O2 (READING FROM INDIRECT READOUT ANALYZER) J1= ";
900 INPUT IN IMAGE "J"; J1
910 J=Y+Z/(1000-J-J1)
915 T=S/60
919 PRINT "TIME = ";T;" MINUTES"
920 PRINT "VE ATPS = ";W;" L/MIN"
925 PRINT "STPD FACTOR = ";U
930 PRINT "VE STPD = ";V;" L/MIN"
935 PRINT "VE BTPS = ";W;" L/MIN"
940 PRINT "CO2 MINUS INSPIRED CO2 = ";Y;" %
945 PRINT "TRUE O2 (%) = ";Z;" %
950 IF W=A9 THEN 120 ELSE 960
960 W=W/1000
965 OXYGEN UPTAKE (ML/KG/MIN)
970 PRINT "OXYGEN UPTAKE = ";O;" ML/KG/MIN"
975 PRINT "CO2 PRODUCTION (L/MIN)"
980 PRINT "CO2 PRODUCTION = ";C4;" L/MIN"
985 PRINT "ARE YOU FINISHED? TYPE YES OR NO: ";
990 INPUT IN IMAGE "Y"; Y
### SYMBOLS AND CONSTANTS USED IN O₂/UPTAKE PROGRAM

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Statement No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A7</td>
<td>Water Vapor Pressure Constant (3.2437814)</td>
</tr>
<tr>
<td>A9</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>B</td>
<td>Intercept for Inspired CO₂ Curve</td>
</tr>
<tr>
<td>B1</td>
<td>Intercept for Expired CO₂ Curve</td>
</tr>
<tr>
<td>B2</td>
<td>Intercept for Inspired &amp; Expired CO₂ Curve</td>
</tr>
<tr>
<td>C</td>
<td>Water Vapor Pressure Constant (5.88826X10⁻³)</td>
</tr>
<tr>
<td>C4</td>
<td>Expired CO₂ Reading from Indirect Readout Analyzer</td>
</tr>
<tr>
<td>C7</td>
<td>Water Vapor Pressure Constant (1.170239X10⁻²)</td>
</tr>
<tr>
<td>C9</td>
<td>Prompt for Conversational Mode of Input</td>
</tr>
<tr>
<td>D</td>
<td>Date</td>
</tr>
<tr>
<td>D7</td>
<td>Water Vapor Pressure Constant (2.1878462X10⁻³)</td>
</tr>
<tr>
<td>D5</td>
<td>Respiratory Valve Dead Space (LITERS)</td>
</tr>
<tr>
<td>E5</td>
<td>Ergometer Load (Watts)</td>
</tr>
<tr>
<td>F</td>
<td>Expired O₂ Reading from Indirect Readout Analyzer</td>
</tr>
<tr>
<td>F9</td>
<td>Branch in Program for Exiting</td>
</tr>
<tr>
<td>G</td>
<td>Gas Temperature (CELSIUS)</td>
</tr>
<tr>
<td>H</td>
<td>Inspired CO₂, Constant or Direct Reading (%)</td>
</tr>
<tr>
<td>H1</td>
<td>Inspired CO₂ Reading from Indirect Readout Analyzer</td>
</tr>
<tr>
<td>J</td>
<td>Inspired O₂, Constant or Direct Reading</td>
</tr>
<tr>
<td>J1</td>
<td>Inspired O₂ Reading from Indirect Readout Analyzer</td>
</tr>
<tr>
<td>K</td>
<td>Inspired CO₂/N₂ (%)</td>
</tr>
<tr>
<td>M</td>
<td>Slope for Inspired CO₂ Curve</td>
</tr>
<tr>
<td>M1</td>
<td>Slope for Expired CO₂ Curve</td>
</tr>
<tr>
<td>M2</td>
<td>Slope for Inspired and Expired O₂ Curve</td>
</tr>
<tr>
<td>N</td>
<td>Branch in Program for Inspired Air Measurements</td>
</tr>
<tr>
<td>O</td>
<td>Oxygen Uptake (L/Min)</td>
</tr>
<tr>
<td>O1</td>
<td>Oxygen Uptake (ML/KG/Min)</td>
</tr>
<tr>
<td>O3</td>
<td>VE BTPS (L/Min)</td>
</tr>
<tr>
<td>P</td>
<td>Barometric Pressure (Torr)</td>
</tr>
<tr>
<td>P7</td>
<td>Water Vapor Pressure Constant (318.167 INT. ATM)</td>
</tr>
<tr>
<td>P8</td>
<td>Water Vapor Pressure (INT. ATMOSPHERES)</td>
</tr>
<tr>
<td>Q</td>
<td>Print in Image Statement</td>
</tr>
<tr>
<td>R</td>
<td>Respiratory Rate (BREATHS/MIN)</td>
</tr>
<tr>
<td>S</td>
<td>Time (Seconds)</td>
</tr>
<tr>
<td>SS</td>
<td>Subject's Name</td>
</tr>
<tr>
<td>T</td>
<td>Time (Minutes)</td>
</tr>
<tr>
<td>T8</td>
<td>Gas Temperature, KELVIN (°C + 273.16)</td>
</tr>
<tr>
<td>TS</td>
<td>Treadmill Speed</td>
</tr>
<tr>
<td>U</td>
<td>STPD Factor</td>
</tr>
<tr>
<td>V</td>
<td>VE STPD (L/Min)</td>
</tr>
<tr>
<td>V1</td>
<td>Respiratory Gas Meter Reading, Initial (LITERS)</td>
</tr>
<tr>
<td>V2</td>
<td>Respiratory Gas Meter Reading, Final (LITERS)</td>
</tr>
<tr>
<td>V3</td>
<td>Respiratory Gas Meter Correction (LITERS)</td>
</tr>
<tr>
<td>W</td>
<td>VE ATPS (L/Min)</td>
</tr>
<tr>
<td>WS</td>
<td>Body Weight (kg)</td>
</tr>
<tr>
<td>X</td>
<td>True CO₂ (%)</td>
</tr>
<tr>
<td>X8</td>
<td>647.27-T8</td>
</tr>
<tr>
<td>Y</td>
<td>Expired CO₂ from Direct Readout Analyzer (L)</td>
</tr>
<tr>
<td>Y5</td>
<td>Net CO₂ (%)</td>
</tr>
<tr>
<td>Z</td>
<td>Expired O₂ from Direct Readout Analyzer (L)</td>
</tr>
<tr>
<td>Z8</td>
<td>LOG₁₀ P7/P8</td>
</tr>
</tbody>
</table>

FIG. 3. Symbols and constants used in the program.
ENTER THE COLUMN 1 VARIABLES FIRST
? "3/30/77", SUBJECT, 66.42, 175, NO, 60, 76.5, 0, 1.066, 0, 27.3, 765.3, 40

DATE = 3/30/77

SUBJECT =

BODY WEIGHT (KG) = W$ = 66.42
ERGOMETER LOAD (WATTS) = E$ = 175
TREADMILL SPEED (MPH) = T$ = NO

TIME, GAS COLLECTION (SECONDS) = S = NO SECONDS
RESP. GAS METER READING, FINAL = V2 = 76.5 LITERS
RESP. GAS METER READING, INITIAL = V1 = 0 LITERS
RESP. GAS METER CORRECTION = V3 = 1.066 LITERS
RESP. VALVE DEAD SPACE = D$ = 0 LITERS
GAS TEMPERATURE = G = 27.3 CELSIUS
BAROMETRIC PRESSURE = P = 765.3 MM HG
RESPIRATION RATE = R$ = 40 BR/MIN
WATER VAPOR PRESSURE = P8 = 27.208617 MM HG

EXPIRED CO2, AS %, FROM DIRECT READOUT ANALYZER (TYPE (NO) IF NOT MEASURED) FCO2 Y = 3.99
EXPIRED O2, AS %, FROM DIRECT READOUT ANALYZER (TYPE (NO) IF NOT MEASURED) FO2 Z = NO
EXPIRED O2 (READING FROM INDIRECT READOUT ANALYZER) F = 657

WERE INSPIRED CO2 AND O2 MEASURED? TYPE YES OR NO: NO

INSPIRED CO2 H = .030 %
INSPIRED O2 J = 20.93 %
EXPIRED CO2 Y = 3.99 %
EXPIRED O2 Z = 16.429403 %

TIME = 1 MINUTES
VE ATPS = 81.549 L/MIN
STPD FACTOR = .88273116
VE STPD = 71.985843 L/MIN
VE BTPS = 87.109995 L/MIN
FCO2 MINUS INSPIRED CO2 = 3.96 %
FO2 = 16.429403 %
RE = .85275936
TRUE O2 = 4.6437485 %
CO2 PRODUCTION = 2.8506394 LITERS PER MINUTE
OXYGEN UPTAKE = 3.3428415 LITERS PER MINUTE
OXYGEN UPTAKE = 59.328839 ML/KG/MIN

ARE YOU FINISHED? TYPE YES OR NO:

FIG. 4. Sample printout of O2 uptake computation.
Fig. 5. Comparison of oxygen uptake calculated with the computer program and the nomograph method.