Design of Experiment: Efficiency difference between 173 and 180 steps per minute?

Purpose:
To investigate which of the cadences produces the lowest heart rate when running a fixed course at the same speed within the aerobic range.

Background:
When the cadence is increased it is sometimes felt like more work that makes you loose your breath. This sensation may be due to either the unusual movements or an unconscious increase of speed, but it could also simply be because more movements require more energy. In this experiment it is attempted to answer this question by having a person (me) used to both running at 173 and 180 steps per minute run the same course at the same speed. The average heart rate is taken as a measure of the effort, since the tests are done in the aerobic range, but still the average heart rate increases with the duration of the run among other things due to the change of “fuel” on longer runs and dehydration. To minimize variations between tests two test are carried out each day with all tests done in the morning on an empty stomach and sequence of the tests are reversed each day. Further one complete test is done as a warm-up each day and this run is done with a cadence different from the subsequent test in order that each test always is a change of cadence from the previous run (e. g. one day warm-up at 173, first test at 180, second test at 173, next day warm-up at 180, first test at 173 and second test at 180).

Method:
Based on a test run where it is attempted to hold the heart rate constant a base pacing is established for an approximately 4 km course. This pace is used with Garmin Virtual Partner to try to run all subsequent tests at the same pace. It is attempted to stay within +/- 20 meter from the virtual partner. The average heart rate from the test is determined from Sporttrack to one decimal.

Calculations:
The heart rates are used as the results in a multiple linear regression where the variables are cadence (173/180), test sequence (0/1/2 as in warm up, 1st test and 2nd test) and a variable representing the day of the test (to account for the possible training effect of 12 km daily runs). Thus it is possible to eliminated the variance from sources other than cadence.

The total data set is here:
https://docs.google.com/spreadsheet/ccc?key=0Ar5bBS-G-ZfLdGd0aXdCNnE5WHlpbEVCRnNkYkkzWUE&hl=da

A picture representing all data:

Date	Trial	Type	Cadence	Pulse rate
28-07-2011	1	0	180	128,1
28-07-2011	1	1	173	132,7
28-07-2011	1	2	180	136,2
30-07-2011	2	0	173	131,2
30-07-2011	2	1	180	138,3
30-07-2011	2	2	173	139,8
04-08-2011	3	0	173	125,1
04-08-2011	3	1	180	135,6
04-08-2011	3	2	173	138,0
13-08-2011	4	0	180	129,2
13-08-2011	4	1	173	138,8
13-08-2011	4	2	180	144,1
25/08/2011	5	0	173	127,8
25/08/2011	5	1	180	137,9
25/08/2011	5	2	173	138,8
09-09-2011	6	0	180	144,4
09-09-2011	6	1	173	146,9
09-09-2011	6	2	180	147,5

The average pulse rates for 173 and 180 respectively (disregarding warm-up) are 139.2 and 139.9.
If the warm-up trials are counted in the figures are 135.5 and 137.9.
The average pulse rates for the three types of trial (warm-up, 1st and 2nd) are 131.0, 138.4 and 140.7 respectively.

By doing a multiple linear regression by means of R in the first case the following is obtained:

```
Residuals:
    Min      1Q  Median      3Q     Max
-4.3914 -1.6029 -0.1557  2.1000  4.1810

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 110.0390    44.8140   2.455  0.03960 *
Trial         1.8943     0.5189   3.651  0.00649 **
Type          2.3667     1.7724   1.335  0.21852
Cadence       0.1095     0.2532   0.433  0.67676
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.07 on 8 degrees of freedom
Multiple R-squared: 0.6566,     Adjusted R-squared: 0.5278
F-statistic: 5.099 on 3 and 8 DF,  p-value: 0.02912
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This basically indicates that the best equation that can be written to cover all the results (disregarding warm-up) is:
Pulserate = 110 + 1.89 * Trial + 2.37 * Type + 0.11 * Cadence
Taking the figures from the last line is the picture above this would be:
Predicted pulse rate = 110 + 1.89 * 6 + 2.37 * 2 + 0.11 * 180 = 145,9
It appears that the trials (1-6) are significantly different (I probably had a slight fever on the 6th trial) but the difference between 1st and 2nd trial (Type) or between cadences are not significant.

Counting in the warm-up trials:

```
Residuals:
     Min       1Q   Median       3Q      Max
-5.82039 -2.53896 -0.01336  2.28262  6.57114

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  68.2418    48.7876   1.399  0.18365
Trial         1.9595     0.5665   3.459  0.00383 **
Type          4.8833     1.1843   4.123  0.00103 **
Cadence       0.3213     0.2764   1.162  0.26455
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.102 on 14 degrees of freedom
Multiple R-squared: 0.6861,     Adjusted R-squared: 0.6188
F-statistic:  10.2 on 3 and 14 DF,  p-value: 0.000804
```

Now the differences between Types (warm-up, 1st and 2nd) are significant so that in average the pulse rate increases with 4.8833 going from warm-up to 1st trial or from 1st trial to 2nd trial. But the cadence difference is still not significant. The coefficient of 0.3213 works out to a difference of (180-173) * 0.3213 = 2.2 almost as the raw figures above (137.9-135.5 = 2.4).

Additional information: (added September 11th 2011)
Length of the course: 4.17 km (round trip)
Body weight: 75 kg
Loss in weight by running a test (14 km total including warming up and cooling down): 1.5 kg
Body height: 181 cm
Change in altitude on course app. 100 m
Running speed: 8.3 km/h
Running to the course (0.5 km) was done with 180 spm when the warm-up was 173 and vice versa. Thus even the warm-up was a change of cadence.
Subjective evaluation: Change from 180 to 173 was always perceived as increase in effort and an immediate feel of more “strain” in the legs. At the end of the course (especially at the end of

the last round trip) the legs felt stiff with 173. I did not have that feeling with 180 and changing from 173 to 180 felt like relaxing.