

Video Article

Using Continuous Data Tracking Technology to Study Exercise Adherence in Pulmonary Rehabilitation

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Abstract

Pulmonary rehabilitation (PR) is an important component in the management of respiratory diseases. The effectiveness of PR is dependent upon adherence to exercise training recommendations. The study of exercise adherence is thus a key step towards the optimization of PR programs. To date, mostly indirect measures, such as rates of participation, completion, and attendance, have been used to determine adherence to PR. The purpose of the present protocol is to describe how continuous data tracking technology can be used to measure adherence to a prescribed aerobic training intensity on a second-by-second basis.

In our investigations, adherence has been defined as the percent time spent within a specified target heart rate range. As such, using a combination of hardware and software, heart rate is measured, tracked, and recorded during cycling second-by-second for each participant, for each exercise session. Using statistical software, the data is subsequently extracted and analyzed. The same protocol can be applied to determine adherence to other measures of exercise intensity, such as time spent at a specified wattage, level, or speed on the cycle ergometer. Furthermore, the hardware and software is also available to measure adherence to other modes of training, such as the treadmill, elliptical, stepper, and arm ergometer. The present protocol, therefore, has a vast applicability to directly measure adherence to aerobic exercise.

Video Link

The video component of this article can be found at <http://www.jove.com/video/50643/>

Introduction

Pulmonary rehabilitation (PR) combines exercise training, patient education and psychosocial support, and is widely recognized as a cornerstone in the management of pulmonary disease¹⁻⁵. The goals of PR are to reduce symptoms, optimize functional status, improve health-related quality of life, and reduce health care costs^{4,5}. In a meta-analysis of 31 randomized controlled trials in chronic obstructive pulmonary disease (COPD), PR was shown to significantly improve exercise capacity, reduce dyspnea and fatigue, improve emotional function and enhance patients' sense of control over their condition⁶. Furthermore, evidence documents its effectiveness in reducing respiratory exacerbations⁷ and days spent in hospital⁸⁻¹³. Exercise training is considered the key to successful PR since it is responsible for much of the benefits associated with this intervention³⁻⁵. However, a major issue for several patients is adhering to the recommended amount or level of exercise. Nonadherence to recommended treatment may result in the failure of therapeutic interventions as well as inefficient use of health resources¹⁴.

According to the World Health Organization, the term "adherence" refers to the extent to which a person's behavior coincides with recommendations given by a health care professional¹⁵. To date, adherence to exercise training in rehabilitation settings has been largely assessed as either the rate of participation (*i.e.* registration to the program), the rate of completion (*i.e.* finishing the program), or the rate of attendance (*i.e.* number of exercise sessions attended)¹⁶⁻¹⁸. At present, no "gold standard" exists for measuring adherence¹⁵ and current methods do not allow for great precision. Furthermore, depending on the selected method, rates of adherence to PR have shown large variability¹⁶⁻¹⁹. For example, Hogg *et al.*¹⁶ measured adherence in COPD patients as the ratio between those who completed the program to those referred and found a low adherence of approximately 40%. However, other PR studies that have used attendance rates demonstrated, on average, a 90% adherence^{10,20,21}. The lack of homogeneity in calculating adherence makes it difficult to compare results between studies. Another concern is the lack of precision with the existing calculation methods; attendance to an exercise training session does not guarantee adherence to the prescribed intensity. This gap in information led us to investigate how adherence could be calculated in a more precise way.

Recent advances in fitness equipment technology have allowed for continuous data tracking, which can be used to monitor adherence to a prescribed aerobic training intensity during individual exercise sessions in a PR context. More specifically, data tracking hardware and software

permits for second-by-second recording of duration, speed, level, wattage, pace, heart rate, distance, calorie consumption, VO_2 , METS, and calories, and provides averages of all variables with the exception of level and VO_2 . The main advantage of this technology is the ability to record continuous detailed measures, which allows for the precise calculation of adherence to prescribed exercise versus previously reported general attendance or completion rates. This procedure can be of value for any study examining the impact of one or several aerobic exercise training programs. Using this technology, patient adherence to a prescribed intensity can be assessed by the percent time spent at a specified wattage, level, speed, or heart rate during the training phase of each session. For our investigations, adherence to an exercise training protocol has been defined as the percent time spent within a specified target heart rate range. Since heart rate response at a given submaximal workload decreases as cardiorespiratory fitness increases, this approach ensures that patients remain at the same relative (versus absolute) training intensity throughout the program. The present protocol describes in detail how continuous data tracking technology can be used to precisely measure adherence to a prescribed target heart rate range.

Protocol

Once data is collected, a single file per subject per session of raw data is obtained. Using statistical software, all sessions per subject are combined into a single file. Subsequently, the target intensity must be calculated for each subject. The adherence rate to that target intensity can then be calculated per session per subject, for each session for all subjects combined, or per group.

1. Data Collection (carried out by personnel supervising the training session)

1. Minimize electrical interference by turning off wireless devices (e.g. cell phones, Wi-Fi, etc.) and minimize crosstalk by ensuring the heart rate monitors and equipment are at least 1 meter apart. Refer to **Figure 1** for placement of heart rate transmitter.
2. Turn on the data tracking software. Press start on the aerobic equipment and train the participant at the target intensity. For example, in our studies, participants are asked to train within ± 5 beats/min of their target heart rate. Refer to **Figure 2** for CardioMemory.
3. Collect data second-by-second for each participant for each rehabilitation session. Collected data includes the following: subject ID, duration (hhmmss), level of intensity (1-30), workload (watts), pedaling speed (revolutions/minute), distance (km), pace (mm:ss/km), heart rate (beats/minute), estimated oxygen consumption (VO_2 , ml/min/kg), metabolic equivalent of physical effort (METs), estimated energy expenditure (kcal/hour), and estimated energy consumed (kcal). See **Figure 3**.
4. Press stop on the aerobic equipment. Click "save" to upload the data to CardioMemory. Click "export" to save the document outside of CardioMemory. The document will be in .csv format and will automatically include the date of the session.

2. Data Extraction

CardioMemory software does not allow for the distinction of various exercise-training phases. As such, the data obtained must be exported to a statistical software in order to eliminate the phases that are not of interest (e.g. warm-up and cool-down), merge the data files, and compare achieved against target intensity.

1. Open statistical analysis software to import excel file. Procedure: *File* \rightarrow *Open* \rightarrow *Data* \rightarrow In "Open Data" window, select *All Files* in the dropdown menu of "Files of Types" \rightarrow Select Excel.xls file \rightarrow *Open* \rightarrow In "Opening Excel Data Source" window click *OK*.
2. Save the data file in a statistical analysis software. See **Figure 4** for a sample database.
3. Eliminate the nontraining phases, i.e. warm-up and cool-down, if the interest is time spent at the target intensity during the training phase.
 1. Eliminate warm-up phase (e.g. first 10 min):
 1. To recode duration, create a variable to identify every second as 1. Procedure: *Transform* \rightarrow *Recode into Different variables...* \rightarrow In "Recode into Different Variables" window, select *Duration_A* \rightarrow click arrow \rightarrow Identify "Output Variable Name" (e.g. *tempo*) \rightarrow *Change* \rightarrow Click on *Old and New Values* \rightarrow Under "Old Value", select *Value:* and enter 0 \rightarrow Under "New Value", Select *Value:* and enter 0 \rightarrow *Add* \rightarrow Under "Old Value", select *All other values* then click on *Value:*, under "New Value" and enter 1 \rightarrow *Add* \rightarrow *Continue* \rightarrow *OK*.
 - RECODE Duration_A (0=0) (ELSE=1) INTO Tempo.
 - EXECUTE.
 2. Create a second temporary variable. Procedure: *Transform* \rightarrow *Shift Values* \rightarrow Select *tempo* \rightarrow Click arrow \rightarrow Under "Name:" type temporary variable (e.g. *tempo2*) \rightarrow *Change* \rightarrow *OK*.
 - SHIFT VALUES VARIABLE=Tempo RESULT=Tempo2 LAG=1.
 3. To start *tempo2* at 0, it must be recoded. Procedure: *Transform* \rightarrow *Recode into Same Variables* \rightarrow Select *tempo2* \rightarrow Click arrow \rightarrow Click *Old and New Values* \rightarrow Under "Old Value", select *System-Missing* \rightarrow Under "New Value", select *Value:* and enter 0 \rightarrow *Add* \rightarrow *Continue* \rightarrow *OK*.
 - RECODE Tempo2 (SYSMIS=0).
 - EXECUTE.
 4. Sum the seconds starting from zero. Procedure: *Transform* \rightarrow *Compute Variable* \rightarrow Under "Target Variable:" type *tempo* \rightarrow Under "Numeric Expression" type *lag (tempo) + 1* \rightarrow *IF...* \rightarrow Select *Include if case satisfies condition:* \rightarrow Type *tempo2 > 0* \rightarrow *Continue* \rightarrow *OK*.
 - IF (Tempo2 > 0) Tempo=Lag (tempo) + 1.
 - EXECUTE.
 5. To eliminate the first 10 min of warm-up, remove tempo data that precedes 599 seconds. Procedure: *Data* \rightarrow *Select cases...* \rightarrow In "Select Cases" window, under "Select", choose "If condition is satisfied" \rightarrow *If...* \rightarrow In "Select Cases: If" window, insert equation *tempo > 599* \rightarrow *Continue* \rightarrow Under "Output", choose *Delete unselected cases* \rightarrow *OK*. See **Figure 5**.

- FILTER OFF.
 - USE ALL.
 - SELECT IF (tempo > 599).
 - EXECUTE.
2. Eliminate cool-down phase (e.g. last 5 minutes):
 1. Sort data in descending order for *Duration_A* to bring the cool-down phase to the top of the database, as SPSS removes data from the top of the file onwards. Procedure: *Data* → *Sort Cases* → In "Sort Cases" window, select *Duration_A* → click arrow → In "Sort Order" menu select *Descending* → *OK*.
 - SORT CASES BY *Duration_A(D)*.
 2. Recode *Duration_A* to identify every second as 1. Procedure: *Transform* → *Recode Into Different variables...* → In "Recode into Different Variables" window, select *Duration_A* → click arrow → Identify "Output Variable Name" (e.g. *tempoA*) → *Change* → Click *Old and New Values* → Under "Old Value", select *Value:* and enter 0 → Under "New Value", select *Value:* and enter 0 → *Add* → Select *All other values* under "Old Value", then click on *Value:* under "New Value" and enter 1 → *Add* → *Continue* → *OK*.
 - RECODE *Duration_A* (0=0) (ELSE=1) INTO *TempoA*.
 - EXECUTE.
 3. Create a second temporary variable. Procedure: *Transform* → *Shift Values* → Select *tempoA* → Click arrow → Under "Name:" type temporary variable (e.g. *tempoA2*) → *Change* → *OK*.
 - SHIFT VALUES VARIABLE=*TempoA* RESULT=*TempoA2* LAG=1.
 4. To start *tempoA2* at 0, it must be recoded. Procedure: *Transform* → *Recode into Same Variables* → Select *tempoA2* → Click arrow → Click *Old and New Values* → Under "Old Value", select *System-Missing* → Under "New Value", select *Value:* and enter 0 → *Add* → *Continue* → *OK*.
 - RECODE *TempoA2* (SYSMIS=0).
 - EXECUTE.
 5. Sum the seconds of the *tempoA* variable. Procedure: *Transform* → *Compute Variable* → Under "Target Variable:" type *tempoA* → Under "Numeric Expression" type $\text{lag}(\text{tempoA})+1$ → *IF...* → Select *Include if case satisfies* condition: → Type $\text{tempoA2} > 0$ → *Continue* → *OK*.
 - $\text{IF}(\text{TempoA2} > 0) \text{TempoA} = \text{Lag}(\text{tempoA}) + 1.$
 - EXECUTE.
 6. To eliminate the cool-down phase (i.e. 5 min), remove tempo data that precedes 299 seconds. Procedure: *Data* → *Select cases...* → In "Select Cases" window, under "Select", choose "If condition is satisfied" → *If...* → In "Select Cases: If" window, insert equation $\text{tempoA} > 299$ → *Continue* → under "Output", choose *Delete unselected cases* → *OK*. See **Figure 6**.
 - FILTER OFF.
 - USE ALL.
 - SELECT IF ($\text{tempoA} > 299$).
 - EXECUTE.
 3. Identify the session number (or date) associated with the dataset. Create and name a new variable (e.g. *Session*). Procedure: *Transform* → *Compute Variable* → In compute variable window under *Target Variable*, type *Session* → click *Type & Label* to open "Compute Variable: Type an..." window → under "Type" select *String* → *Continue* → under *String Expression* type '1' → *OK*. See **Figure 7**.
 - STRING *Session* (A8).
 - COMPUTE *Session*='1'.
 - EXECUTE.
 4. Save the modified SPSS document in a new file (example: *subjectID_session#*).
 5. Repeat the above procedure for all remaining sessions for the same subject.

3. Data Merging - Single Participant

1. To merge all sessions into a single SPSS database, open participant's first session (i.e. *subjectID_session1*).
2. Merge remaining sessions to the current file. Procedure: *Data* → *Merge Files* → *Add Cases* → in "Add Cases to *subjectID_session1.sav*" window, click *Browse* and choose file *subjectID_session2* → *Open* → *Continue* → in the "Add Cases from ..." window click *OK*. Repeat for all remaining sessions. See **Figure 8**.
 - ADD FILES /FILE=*
 - /FILE='SubjectAB001_Session1.sav'.
 - EXECUTE.
3. Add a column which contains the subject's ID number. Procedure: *Transform* → *Compute Variable* → In "Compute Variable" window under *Target Variable*, type *SubjectID* → click *Type & Label* to open "Compute Variable: Type an..." window → under "Type" select *String* → *Continue* → under *String Expression* type '*SubjectID*' (e.g. '*AB001*') → *OK*. See **Figure 9**.

- STRING Subject_ID (A8).
 - COMPUTE Subject_ID='AB001'.
 - EXECUTE.
4. Add a column that contains the subject's target intensity (e.g. target heart rate [THR]). Procedure: *Transform* → *Compute Variable* → In "Compute Variable" window under *Target Variable*, type THR → click *Type & Label* to open "Compute Variable: Type an..." window → under "Type" select *Numeric* → *Continue* → under *Numeric Expression* type THR (e.g. 110) → OK. See **Figure 10**.
 - STRING THR (A8).
 - COMPUTE THR='110'.
 - EXECUTE.
 5. Save database under a different file name (e.g. *SubjectAB001_session1-36*).
 6. Repeat for all remaining participants. At this point, each participant will have a database containing all sessions.

4. Data Merging - Grouping Participants

1. To group several participants into a single database, open participant's file (i.e. *subjectID_session1-36*).
2. Merge the remaining participants to the current file. Procedure: *Data* → *Merge Files* → *Add Cases* → in "Add Cases to *SubjectAB001_session1-36.sav*" window, click *Browse* and choose file *SubjectCD002_session1-36* → *Open* → *Continue* → in the "Add Cases from ..." window click *OK*. Repeat for all participants that you wish to group. See **Figure 11**.
 - ADD FILES /FILE=*
 - /RENAME (AB001=d0)
 - /FILE='SubjectAB001_Session1-36.sav'
 - /RENAME (CD002=d1)
 - /DROP=d0 d1.
 - EXECUTE.
3. Save new database (e.g. *Group01_Subjects001-010*).

5. Identification of Target Intensity (e.g. THR Range)

1. Identify a THR range; click *Transform* → *Compute Variable* → in the "Compute Variable" window under "Target Variable" enter a new variable name (e.g. *Diff_HR_THR*) → "Type & Label..." → in the "Compute Variable: Type an..." select *Numeric* → *Continue* → Under "Numeric Expression" enter equation: $HR - THR$ → OK. This provides us with a new variable.
 - COMPUTE *Diff_HR_THR*= $HR - THR$.
 - EXECUTE.
2. Recode variables to identify whether the HR lies below, above, or within the THR range. Procedure: *Transform* → *Recode Into Different Variables...* → select *Diff_HR_THR* → click arrow → under "Output Variable" under "Name" type *Diff_HR_THR_recoded* → *Change* → *Old and New Values...* → in "Recode Into Different Variables: Old and New Values" window:

Old Value	New Value		Old-->New:
Range: -5 through 5	1	Add	-5 thru 5 --> 1
Range, LOWEST through value: -5	0		Lowest thru -5 --> 0
Range, value through HIGHEST: 5	0		5 thru Highest --> 0
System-missing	System-missing		SYSMIS--> SYSMIS

→ *Continue* → OK. See **Figure 12**.

- RECODE *Diff_HR_THR* (SYSMIS=SYSMIS) (-5 thru 5=1) (Lowest thru -5=0) (5 thru Highest=0) INTO
- *Diff_HR_THR_Recoded*.
- EXECUTE.

6. Calculation of Percent Adherence

1. In *Group01_Subjects001-010* file, calculate all seconds that patients were within the THR range by doing the following: *Data* → *Aggregate* → in "Aggregate Data" window, under "Break Variable(s):" select *subjectID* and *session* → click arrow → under "Summaries of Variable(s):" select *Diff_HR_THR_recoded* → click arrow → OK. A new variable is created with the name *Diff_HR_THR_recoded_mean*.
 - AGGREGATE
 - /OUTFILE=* MODE=ADDVARIABLES
 - /BREAK=Subject_ID Session
 - /*Diff_HR_THR_Recoded_mean*=MEAN(*Diff_HR_THR_Recoded*).
2. Convert the obtained value into a percentage; click *Transform* → *Compute Variable* → under "Target Variable" enter variable name (e.g. *Perc_THR*) → under "Numeric Expression" select *Diff_HR_THR_recoded_mean* → click arrow → multiply the value by 100

$(\text{Diff_HR_THR_recoded_mean} * 100) \rightarrow \text{OK}$. We then obtain adherence as a percentage of time spent within the THR for each subject for each session. See **Figure 13**

- COMPUTE Perc_THR=Diff_HR_THR_Recoded_mean * 100.
 - EXECUTE.
3. To obtain adherence for the percentage of time spent within the THR for each subject for all sessions combined, in "Aggregate Data" window, under "Break Variable(s):" substitute *subjectID* and *session* with only *subjectID*. See **Figure 14**.
 4. To obtain adherence for the percentage of time spent within the THR for each session for all subjects combined, in "Aggregate Data" window, under "Break Variable(s):" substitute *subjectID* and *session* with only *session*.
 5. Save the database under a different file name (e.g. *Group01_Subjects001-010_Aggregate*).

Representative Results

When the protocol is performed correctly, an adherence rate is obtained for each subject for each session (**Figure 13**), for each subject for all sessions (**Figure 14**), and for each session for all subjects combined. An estimate of the time required to complete the above protocol for a single session of one subject is approximately 5 min. Results for adherence can range from 0-100%. Using this information, additional analyses can be performed to determine differences between subjects (*i.e.* sex differences, disease severity, *etc.*), to identify changes over time, and to reveal patterns in adherence. Moreover, the comparison of adherence between groups can be performed; for example, different exercise training programs can be compared. Finally, through further investigation, causes of nonadherence can be identified at specific time points during PR.

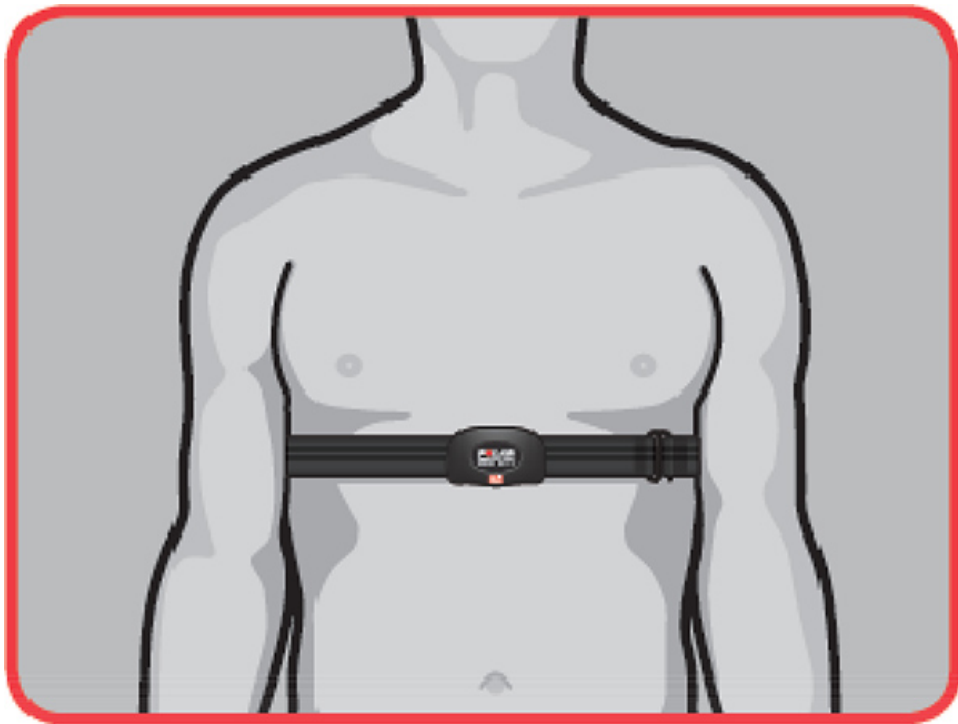


Figure 1. Heart rate transmitter placement. [Click here to view larger image.](#)



Figure 2. Sample of data collected using data tracking software. [Click here to view larger image.](#)

Club Member	AB123	Durat. (hh:mm:ss)	00:21:01
Age (years)	64	Durat. (sec.)	1261
Weight (Kg)	64	Calories (Kcal)	96
Exercise	Bike Med: Quick start	Distance (Km)	6,65
Equipment	BIKE MED	Average HR (B./M.)	91
Date/time	2009-05-06 11:36	P.I.	22
Doctor/Trainer	ADMINISTRATOR Administrator	Avg. Watts (Watt)	46
		Average speed (Rpm)	59
		Mets	3,9
		Pace (mm:ss/km)	00:03:10

Durat. (hh:mm:ss)	Speed (Rpm)	Calorie cons. (Kcal/h)	%HR (%HR)	Level	Watt (Watt)	Pace (mm:ss/km)	HR (B./M.)	VO2 (ml/min/Kg)	Mets (Mets)	Calories (Kcal)	Distance (Km)
00:00:01	37	200	32	1	19	00:00:00	61	10	2,9	0	0
00:00:02	37	200	32	1	19	00:00:00	61	10	2,9	0	0
00:00:03	38	200	32	1	20	00:04:52	61	10,2	2,9	0	0,01
00:00:04	38	200	32	1	20	00:04:52	61	10,2	2,9	0	0,01
00:00:05	39	202	32	1	20	00:04:44	61	10,2	2,9	0	0,01
00:00:06	39	204	32	1	20	00:04:44	60	10,2	2,9	0	0,01
00:00:07	40	202	32	1	21	00:04:37	60	10,3	2,9	0	0,02
00:00:08	40	204	31	1	21	00:04:37	59	10,3	2,9	0	0,02
00:00:09	41	206	31	1	21	00:04:31	59	10,3	2,9	0	0,02
00:00:10	41	206	31	1	21	00:04:31	59	10,3	2,9	0	0,03
00:00:11	41	206	31	1	21	00:04:31	59	10,3	2,9	0	0,03
00:00:12	42	206	31	1	21	00:04:24	59	10,3	2,9	0	0,03
00:00:13	42	206	31	1	21	00:04:24	58	10,3	2,9	0	0,04
00:00:14	43	206	31	1	22	00:04:18	58	10,5	3	0	0,04
00:00:15	44	206	31	1	22	00:04:12	58	10,5	3	0	0,05

Figure 3. Sample of data tracking software output. [Click here to view larger image.](#)

Figure 4 shows a screenshot of the IBM SPSS Statistics Data Editor interface. The window title is "SubjectAB001_session1.sav [DataSet1] - IBM SPSS Statistics Data Editor". The menu bar includes File, Edit, View, Data, Transform, Analyze, Graphs, Utilities, Add-ons, Window, and Help. The toolbar contains various icons for file operations and analysis. The main data grid displays 12 variables: Durat, nhmmss_A, SpeedRpm, Caloriecons Kcal/h, HRbR, Level, WattWatt, Pacemsskm, HRB M, VO2ml/min/Kg, MetsMets, CaloriesKcal, and DistanceKm. The data is organized into 24 rows, with the first row starting at 00:01:00 and the last row at 00:24:00. The status bar at the bottom indicates "IBM SPSS Statistics Processor is ready".

Figure 4. Sample database illustrating a sample of statistical software database. [Click here to view larger image.](#)

Figure 5 shows a screenshot of the IBM SPSS Statistics Data Editor interface, similar to Figure 4 but with 14 variables. The variables are: Durat, nhmmss_A, SpeedRpm, Caloriecons Kcal/h, HRbR, Level, WattWatt, Pacemsskm, HRB M, VO2ml/min/Kg, MetsMets, CaloriesKcal, DistanceKm, Tempo, and Tempo2. The data is organized into 24 rows, with the first row starting at 00:00:00 and the last row at 00:24:00. The last two columns, Tempo and Tempo2, are highlighted with a red border. The status bar at the bottom indicates "IBM SPSS Statistics #98 Not connected - Connections are available".

Figure 5. Sample database illustrating the eliminated warm-up phase. [Click here to view larger image.](#)

Visible: 16 of 16 Variables

	Durat	hhmmss_A	SpeedRpm	Caloriecons	KcalH	HRHR	Level	WattWatt	Pacemsskm	HRB M	VO2mlnsKg	MetasMets	CaloriesKcal	DistanceKm	Tempo	Tempo2	TempoA	TempoA2	var
1	0	17:03:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	82	5.55	1023:00	1.00	300:00	1.00		
2	0	17:02:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.54	1022:00	1.00	301:00	1.00		
3	0	17:01:00	61	240	47	1	31	0:03:02:00	90	11.9	3.4	82	5.54	1021:00	1.00	302:00	1.00		
4	0	17:00:00	61	242	47	1	31	0:03:02:00	90	11.9	3.4	82	5.53	1020:00	1.00	303:00	1.00		
5	0	16:59:00	62	236	47	1	32	0:02:59:00	90	12	3.4	82	5.53	1019:00	1.00	304:00	1.00		
6	0	16:58:00	62	238	47	1	32	0:02:59:00	90	12	3.4	82	5.52	1018:00	1.00	305:00	1.00		
7	0	16:57:00	61	238	47	1	31	0:03:02:00	89	11.9	3.4	82	5.52	1017:00	1.00	306:00	1.00		
8	0	16:56:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.51	1016:00	1.00	307:00	1.00		
9	0	16:55:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.5	1015:00	1.00	308:00	1.00		
10	0	16:54:00	60	236	47	1	31	0:03:05:00	90	11.9	3.4	81	5.5	1014:00	1.00	309:00	1.00		
11	0	16:53:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.49	1013:00	1.00	310:00	1.00		
12	0	16:52:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.49	1012:00	1.00	311:00	1.00		
13	0	16:51:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	81	5.48	1011:00	1.00	312:00	1.00		
14	0	16:50:00	61	236	47	1	31	0:03:02:00	90	11.9	3.4	81	5.48	1010:00	1.00	313:00	1.00		
15	0	16:49:00	61	236	47	1	31	0:03:02:00	90	11.9	3.4	81	5.47	1009:00	1.00	314:00	1.00		
16	0	16:48:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	81	5.47	1008:00	1.00	315:00	1.00		
17	0	16:47:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1007:00	1.00	316:00	1.00		
18	0	16:46:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1006:00	1.00	317:00	1.00		
19	0	16:45:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1005:00	1.00	318:00	1.00		
20	0	16:44:00	61	236	48	1	31	0:03:02:00	91	11.9	3.4	81	5.45	1004:00	1.00	319:00	1.00		
21	0	16:43:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.44	1003:00	1.00	320:00	1.00		
22	0	16:42:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.44	1002:00	1.00	321:00	1.00		
23	0	16:41:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.43	1001:00	1.00	322:00	1.00		
24	0	16:40:00	60	236	47	1	31	0:03:05:00	90	11.9	3.4	81	5.43	1000:00	1.00	323:00	1.00		

Figure 6. Sample database illustrating the eliminated cool-down phase. [Click here to view larger image.](#)

Visible: 17 of 17 Variables

	Durat	hhmmss_A	SpeedRpm	Caloriecons	KcalH	HRHR	Level	WattWatt	Pacemsskm	HRB M	VO2mlnsKg	MetasMets	CaloriesKcal	DistanceKm	Tempo	Tempo2	TempoA	TempoA2	Session
1	0	17:03:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	82	5.55	1023:00	1.00	300:00	1.00	1	
2	0	17:02:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.54	1022:00	1.00	301:00	1.00	1	
3	0	17:01:00	61	240	47	1	31	0:03:02:00	90	11.9	3.4	82	5.54	1021:00	1.00	302:00	1.00	1	
4	0	17:00:00	61	242	47	1	31	0:03:02:00	90	11.9	3.4	82	5.53	1020:00	1.00	303:00	1.00	1	
5	0	16:59:00	62	236	47	1	32	0:02:59:00	90	12	3.4	82	5.53	1019:00	1.00	304:00	1.00	1	
6	0	16:58:00	62	238	47	1	32	0:02:59:00	90	12	3.4	82	5.52	1018:00	1.00	305:00	1.00	1	
7	0	16:57:00	61	238	47	1	31	0:03:02:00	89	11.9	3.4	82	5.52	1017:00	1.00	306:00	1.00	1	
8	0	16:56:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.51	1016:00	1.00	307:00	1.00	1	
9	0	16:55:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	82	5.5	1015:00	1.00	308:00	1.00	1	
10	0	16:54:00	60	236	47	1	31	0:03:05:00	90	11.9	3.4	81	5.5	1014:00	1.00	309:00	1.00	1	
11	0	16:53:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.49	1013:00	1.00	310:00	1.00	1	
12	0	16:52:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.49	1012:00	1.00	311:00	1.00	1	
13	0	16:51:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	81	5.48	1011:00	1.00	312:00	1.00	1	
14	0	16:50:00	61	236	47	1	31	0:03:02:00	90	11.9	3.4	81	5.48	1010:00	1.00	313:00	1.00	1	
15	0	16:49:00	61	236	47	1	31	0:03:02:00	90	11.9	3.4	81	5.47	1009:00	1.00	314:00	1.00	1	
16	0	16:48:00	61	238	47	1	31	0:03:02:00	90	11.9	3.4	81	5.47	1008:00	1.00	315:00	1.00	1	
17	0	16:47:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1007:00	1.00	316:00	1.00	1	
18	0	16:46:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1006:00	1.00	317:00	1.00	1	
19	0	16:45:00	61	238	48	1	31	0:03:02:00	91	11.9	3.4	81	5.46	1005:00	1.00	318:00	1.00	1	
20	0	16:44:00	61	236	48	1	31	0:03:02:00	91	11.9	3.4	81	5.45	1004:00	1.00	319:00	1.00	1	
21	0	16:43:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.44	1003:00	1.00	320:00	1.00	1	
22	0	16:42:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.44	1002:00	1.00	321:00	1.00	1	
23	0	16:41:00	60	238	47	1	31	0:03:05:00	90	11.9	3.4	81	5.43	1001:00	1.00	322:00	1.00	1	
24	0	16:40:00	60	236	47	1	31	0:03:05:00	90	11.9	3.4	81	5.43	1000:00	1.00	323:00	1.00	1	

Figure 7. Sample database illustrating a column added for session number. [Click here to view larger image.](#)

Figure 8 shows a screenshot of the IBM SPSS Statistics Data Editor interface. The window title is "*SubjectAB001_session1.sav [DataSet1] - IBM SPSS Statistics Data Editor". The menu bar includes File, Edit, View, Data, Transform, Analyze, Graphs, Utilities, Add-ons, Window, and Help. The toolbar contains various icons for file operations and analysis. The main data grid displays 17 variables: Durat, nhmms_A, SpeedRpm, Caloriecons, Kcalh, HRHR, Level, WattWatt, Pacemsssmk, HRB M, VO2mlmkg, MetaMets, CaloriesKcal, DistanceKm, Tempo, Tempo2, TempoA, TempoA2, and Session. The Session column is highlighted with a red border. The data rows show values for these variables across multiple sessions.

Figure 8. Sample database illustrating the merged sessions for a single participant. [Click here to view larger image.](#)

Figure 9 shows a screenshot of the IBM SPSS Statistics Data Editor interface. The window title is "*SubjectAB001_session1.sav [DataSet1] - IBM SPSS Statistics Data Editor". The menu bar and toolbar are the same as in Figure 8. The main data grid displays 18 variables: Durat, nhmms_A, SpeedRpm, Caloriecons, Kcalh, HRHR, Level, WattWatt, Pacemsssmk, HRB M, VO2mlmkg, MetaMets, CaloriesKcal, DistanceKm, Tempo, Tempo2, TempoA, Tempo, Session, and SubjectID. The SubjectID column is highlighted with a red border. The data rows show values for these variables across multiple sessions, with SubjectID consistently being 'AB001'.

Figure 9. Sample database illustrating a column added for subject identification number. [Click here to view larger image.](#)

Figure 10 shows a screenshot of the IBM SPSS Statistics Data Editor. The window title is "SubjectAB001_session1.sav [DataSet1] - IBM SPSS Statistics Data Editor". The interface includes a menu bar (File, Edit, View, Data, Transform, Analyze, Graphs, Utilities, Add-ons, Window, Help) and a toolbar. The main area displays a data grid with 19 columns and 23 rows. The columns are: DuratAhmmss_A, SpeedRpm, Caloriecons Kcalh, HRHR, Level, WattWatt, Pacemsskm, HRB M, VO2mlminKg, MetaMets, Calories Kcal, DistanceKm, Tempo, Tempo2, TempoA, Tempo, Session, SubjectID, and THR. The THR column is highlighted with a red border. The data rows show values for each variable, with SubjectID consistently being 'AB001' and THR consistently being '110.00'. The status bar at the bottom indicates "IBM SPSS Statistics Processor is ready" and the system clock shows "14:33".

Figure 10. Sample database illustrating a column added for target heart rate. [Click here to view larger image.](#)

Figure 11 shows a screenshot of the IBM SPSS Statistics Data Editor. The window title is "Group01_Subjects001-010.sav [DataSet1] - IBM SPSS Statistics Data Editor". The interface is similar to Figure 10. The data grid shows 19 columns and 20 rows of data. The columns are: DuratAhmmss_A, SpeedRpm, Caloriecons Kcalh, HRHR, Level, WattWatt, Pacemsskm, HRB M, VO2mlminKg, MetaMets, Calories Kcal, DistanceKm, Tempo, Tempo2, TempoA, Tempo, Session, SubjectID, and THR. The SubjectID and THR columns are highlighted with a red border. The data rows show values for each variable, with SubjectID varying across participants (e.g., AB001, CD002) and THR consistently being '110.00'. The status bar at the bottom indicates "IBM SPSS Statistics Processor is ready" and the system clock shows "14:44".

Figure 11. Sample database illustrating the merged participants' files. [Click here to view larger image.](#)

Figure 12 shows a screenshot of the IBM SPSS Statistics Data Editor interface. The window title is "Group01_Subject001-010.sav [DataSet1] - IBM SPSS Statistics Data Editor". The menu bar includes File, Edit, View, Data, Transform, Analyze, Graphs, Utilities, Add-ons, Window, and Help. The toolbar contains various icons for file operations and analysis. The main data grid displays 21 variables for 23 rows of data. The variables are: Durat_A, SpeedRpm, Caloriecons_Kcalh, HRHR_Level, Watt_Watt, Pacemmskm, HRB_M_VO2ml_minKg_A, Mets_Mets, Calones_Kcal, Distance_Km, Tempo_Tempo, Tempo2_Tempo, TempoA_Tempo, Session_Session, SubjectID_SubjectID, THR_THR, Diff_HR_Thr_Recorded, and Diff_HR_Thr_Recorded. The 'Diff_HR_Thr_Recorded' column is highlighted with a red border. The data shows values for each variable across the 23 rows, with the highlighted column containing values ranging from -19.00 to -20.00.

Figure 12. Sample database illustrating the recorded heart rate variables. [Click here to view larger image.](#)

Figure 13 shows a screenshot of the IBM SPSS Statistics Data Editor interface. The window title is "Group01_Subject001-010.sav [DataSet1] - IBM SPSS Statistics Data Editor". The menu bar includes File, Edit, View, Data, Transform, Analyze, Graphs, Utilities, Add-ons, Window, and Help. The toolbar contains various icons for file operations and analysis. The main data grid displays 23 variables for 23 rows of data. The variables are: Durat_sA, SpeedRpm, Caloriecons_Kcalh, HRHR_Level, Watt_Watt, Pacemmskm, HRB_M_VO2ml_minKg_A, Mets_Mets, Calones_Kcal, Distance_Km, Tempo_Tempo, Tempo2_Tempo, TempoA_Tempo, Session_Session, SubjectID_SubjectID, THR_THR, Diff_HR_Thr_Recorded, Diff_HR_Thr_Recorded, and Perc_Thr_Rec. The 'Diff_HR_Thr_Recorded' and 'Perc_Thr_Rec' columns are highlighted with a red border. The data shows values for each variable across the 23 rows, with the highlighted columns containing values ranging from -6.00 to -9.00 and .30 to .70 respectively.

Figure 13. Sample database illustrating adherence as a percentage of time spent within the target heart rate range for each subject for each session (horizontal red line highlights the change in adherence between sessions for the same subject). [Click here to view larger image.](#)

The screenshot shows a data editor window with a table containing 23 variables. The variables include: Durat (min), Speed (Rpm), Caloriecons (Kcal), HR:HR, Level (Watt), Pacemms (km), HRB M (VO2ml), Meta (Mets), Calories (Kcal), Distance (Km), Tempo, Tempo2, Tempo A, Tempo A2, Session, Subject ID, THR, Diff_HR_THR, Diff_HR_THR_Recoded, Diff_HR_THR_Recoded_mean, and Perc_THR_per_subj. The data rows represent individual sessions for different subjects, with adherence values ranging from 0.87 to 0.91.

Figure 14. Sample database illustrating adherence for the percentage of time spent within the target heart rate range for each subject for all sessions (horizontal red line highlights the difference between subjects). [Click here to view larger image.](#)

Discussion

Continuous data tracking technology enables for a very precise measurement of exercise adherence. This procedure can be easily adapted to other definitions of adherence by replacing target heart rate range with target wattage, level, speed, or MET level. In the present example, the warm-up and cool-down phases were eliminated to isolate the exercise phase because of our specific research objective. Should the warm-up and cool-down phases be of interest to other researchers, step 2.3 ("Eliminate the nontraining phases") can be eliminated from the protocol. Furthermore, the hardware and software is also available to measure adherence to other modes of training, such as the treadmill, elliptical, stepper, and arm ergometer.

When following the above protocol, certain simple steps are critical. First, the CardioMemory software must be started before the exercise equipment (e.g. cycle ergometer) for exercise data to be tracked and subsequently recorded. Should data be lost at this initial step, the data extraction protocol will need to be adjusted accordingly. Secondly, sources of interference must be minimized to reduce the risk of crosstalk and/or lost data. The heart rate monitors communicate wirelessly with the equipment and software. Thus, interference is especially detrimental if using target heart rate to calculate adherence. Finally, it is imperative to select statistical software for the database that has the capacity to permit for large quantities of data. For example, in a study with 10 participants completing 36 sessions at 40 min each, 864,000 rows of data points will be generated. Excel 2007 and later versions have the capacity to contain 1,048,576 rows in a worksheet²³, whereas SAS²⁴ and SPSS²⁵ have no limit for the number of rows. Depending on the total number of data points expected for a given study, the software needs to be selected accordingly.

Despite the notable advantages of this technology, two main limitations exist. The first is data loss, which can result from equipment and/or software failure. As mentioned above, data loss can be due to electrical interference with wireless devices (i.e. cell phones or Wi-Fi), and more specifically interference with the wireless data transmission of heart rate. However, at times, data loss can also be due to unidentifiable causes. A second limitation is that the software does not provide the option of marking or splitting the exercise protocol systematically in order to differentiate/identify different phases. If this option were available, the extraction of the exercise phase of interest could be performed directly in the software, which would limit steps in the adherence calculation protocol. As well, the option of placing markers would be practical for the study of adherence to interval or intermittent training protocols as it would allow for the differentiation of the different phases (e.g. low versus high intensity).

For future perspectives, the use of continuous data tracking technology to precisely quantify adherence will enable researchers to investigate patterns of exercise response to different interventions, identify determinants of adherence, and characterize good and poor adherers. Ultimately, a better understanding of exercise adherence will allow for the optimization of exercise rehabilitation programs.

Disclosures

The authors declare that they have no competing financial interests.

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