Correlation Study of Brachial and Forearm Cardiograph Sensors

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Abstract

Alternative solutions have been suggested to the traditional brachial arm cuff used in polygraphic credibility assessment testing to reduce the vulnerability of the cardiograph sensor data to artifacts that may disrupt the usability of the data, and to reduce level of physical discomfort that may be experienced and reported by polygraph examinees. This study involved the collection of simultaneous time-series recordings of the cardiograph data used in polygraphic credibility assessment testing. Data were obtained using a common form of acquaintance or practice test. Correlations were calculated for two alternative locations for the deployment or attachment of the cardiograph sensor to the examinee. Replacement of recording sensor technology supported by decades of validity research, published statistical models, and exhaustive field experience is a complex task. An ideal solution will be a replacement sensor solution in the form of a drop-in replacement that provides a very high correlation with the replaced sensor when data are of normal, un-artifacted, interpretable quality, while increasing the number of cases for which the cardiograph sensor data remain usable. Results from this study suggest that two alternative cardiograph sensor deployment solutions, leg-cuff and forearm-cuff, may be suitable for drop-in use, and may provide some advantages in terms of improved data quality. However, concerns about potentially serious medical events such as a dislodged thrombosis, regardless of how rare or unlikely its occurrence, should preclude further interest in the use of the leg cuff deployment. Continued interest in the forearm cuff deployment is recommended.

Introduction

Scientific credibility assessment testing – often referred to as polygraph testing, and commonly referred to as lie-detection testing – does not detect or measure lies *per se*, and instead relies on proxy signals to make probabilistic conclusions. In this way, credibility assessment testing, is like other scientific tests that use statistical methods to quantify phenomena that cannot be subject to perfect deterministic observation or direct physical measurement – because they are very tiny, very far away, unobservable due to the passage of time, or simply amorphous.

The traditional array of polygraph sensors was developed to record several different forms of autonomic nervous system activity for which empirical evidence has shown to be correlated with deception and truth-telling at rates for which they can be combined in structural and statistical models that produce classification accuracy rates that significantly exceed both random chance and unassisted human-expert lie detection. Other sensors have been proposed, including central nervous system, ocular, and facial recording technologies. However, the computerized polygraph systems of today continue to make use of autonomic signals, including respiration activity, electrodermal activity, vasomotor activity, and cardiovascular activity.

The cardiovascular sensor holds the greatest similarity to medical device technologies. Indeed, the traditional cardiograph sensor is simply a medical blood pressure cuff used at a sub-occlusive or semi-occlusive level of pressure. The traditional location for the attachment of the cardiograph sensor to the examinee – on the upper arm, over the brachial artery – is also borrowed from the medical profession. However, whereas measurement of blood pressure in a medical setting may take one or two minutes, polygraph testing may consist of a sequence of questions that may require five to seven, or more, minutes to complete. And the question sequences will be repeated multiple times. Moreover, some examinations may consist of multiple series of test questions, each of which may be repeated several times. It is therefore not surprising that the cardiograph sensor has been described by some polygraph examinees as a source of physical discomfort during testing. For this reason, there has been some interest in a cardiograph sensor solution that can acquire and record the signal of interest with less physical discomfort to the examinee. An improved sensor may improve the polygraph signals and may also permit the examinee to experience less distraction during testing.

Some alternatives have been suggested as potential replacements for the brachial arm cuff. These include a fingertip cardio sensor (Cestaro & Dollins, 1997) that was reported as not a viable alternative for the brachial arm cuff. Deployment of the cardiograph sensor on the lower leg has also been suggested – though this has been discouraged since medical professionals suggested that there may be increased risk for causing a dislodged thrombosis with this method [See Handler, Nelson, and Floyd (2016) for discussion.].[1] Thrombosis is a rare, though potentially fatal, medical emergency. No published or anecdotal events of dislodged thrombosis are reported to have occurred during polygraph testing. However, the cautionary statements of medical professionals should not be taken lightly, and the continued use of the leg cuff has been discouraged in recent years.

Another proposed solution is the deployment of the cardiograph sensor on the forearm. The forearm location is reported as less uncomfortable than the brachial arm cuff. Whereas the upper arm includes large and highly sensitive neurons, especially on the medial side of the arm, the forearm engages in frequent contact with the environment and may be more tolerant of several minutes of semi-occlusive pressure during polygraph testing. The forearm has the additional advantage of better

[1]Thrombosis, also thromboembolism, can occur with persons of any age. Risk for dislodged thromboembolism is increased with prolonged sedentary activity, such as while traveling or other conditions involving reduced blood circulation. A potential hazard is that a dislodged thrombosis travels to the lungs, with the potential for blockage of circulation, damage to the lungs, and even death (CDC, 2022, June 9).

social proxemics – meaning that it may be less physically intrusive and more comfortable for examiners to work effectively with the forearm cuff.

Replacement of a sensor, within the traditional array of polygraph sensors, is not uncomplicated. One approach to such replacement would be to obtain a volume of data, using the new sensor, that is sufficient to replace the data supporting the old sensor. This will include the recalculation of both the structural models and effect sizes. Another approach will be to hope for a *drop-in replacement* of the old sensor – without the need to replicate or repeat existing development and validation studies. A satisfactory drop-in replacement will require a very high correlation between data from the old and replacement sensors. This project is intended to investigate potential alternative placements or locations as a drop-in replacement for the deployment of the traditional brachial arm cuff, including the use of the cardiograph sensor on the lower leg[2] and the forearm.

Method

Polygraph data were collected for a cohort of young adult polygraph subjects using the normal array of polygraph recording sensors, along with an additional data interface device to record data for a second cardiograph sensor. Two sets of data were collected using the two simultaneous cardiograph sensors.

Participants

Participants include 16 young adults ages 25 to 37 with no known medical or mental health problems. There were 7 female and 9 male participants. All of whom were employed by the government of a Latin American country.

Instrumentation

Data were collected using a Dell portable laptop computer running the Windows 7 operating system connected to the LX5000 data acquisition system (Lafayette Instrument Co.), which includes recording channels for thoracic and abdominal respiration, cardiovascular activity, electrodermal activity, physical activity, and vasomotor activity. The data interface device was integrated with the LXSoftware version 11.4.1. An additional data acquisition system, an LX4000 (also from Lafayette Instrument Co., Lafayette, IN) was also integrated with the recording software. In this way, data could be captured simultaneously for the traditional cardiograph sensor deployed on the upper arm over the brachial artery, and a second cardiograph sensor deployed on the lower leg and forearm.

Data Collection

Data collection took place during 2015 and was supervised by the authors. Two samples were recorded for each participant. The recording activity consisted of a common polygraph acquaintance test – a form practice test used to familiarize the examinee and ascertain the correct functionality of the instrument prior to recording data for CQT formats. The acquaintance test format was the known-solution test, in which the subject is presented with a series of stimulus questions about their surname, and where they are instructed to answer incorrectly in response to the question that actually includes their surname. [Refer to Nelson, Prado, Blalock and Handler (2018) for detailed information on the history and use of the known solution acquaintance test.]

Two samples of data were obtained from each participant. One sample included the traditional brachial arm cuff with the second cardiograph sensor deployed on the lower leg. Cuff pressures for the brachial cuff were adjusted to 65mmHg during testing (Nelson, 2016). This pressure was selected because it is less than the average diastolic blood pressure (120/80mmHg), and therefore assumed to be semi-occlusive or sub-occlusive, and still sufficient to provide usable polygraphic

[2] Continued use of the leg cuff procedure is not recommended due to concerns expressed by medical professionals involving the potential for some increase in the risk of thrombosis. Leg cuff data are included in this analysis because data were available prior to the change in recommended procedures, and to show the potential advantages and differences inherent to different procedural solutions.

data while imposing less physical discomfort on the examinee than a high-pressure level. Cuff pressures for the leg cuff were increased to 90mmHg to improve the data quality, while still producing less reported physical discomfort to the examinees. Leg cuff pressures were close to the average mean arterial pressure (MAP)[3], and were assumed to remain sub-occlusive or semi-occlusive. The other sample included the traditional brachial arm cuff with the second cardiograph sensor deployed on the forearm. Forearm cuff pressures were limited to 65mmHg, well under average MAP, and produce less reported physical discomfort to the examinee than the traditional brachial arm cuff. The two cuffs were deployed on opposing sides, right and left, for each sample. Sixteen samples were obtained using the alternative leg cuff, and sixteen samples were obtained using the alternative forearm cuff.

To better understand the potential similarity and difference of data from different instruments operating simultaneously, a small number of cases were recorded using two forearm cuffs place on the right and left sides of the subject. Graphic results are shown in Appendix A for two cases for which the mean r = .959.

Analysis

Data were exported to the NCCA ASCII format (Editorial Staff, 2019) and imported to the R Language (R Core Team, 2022) for statistical computing. For each case, correlation coefficients were calculated for the recorded time-series data from the two cardio cuffs. Time series data were processed at 30 samples per second and were not subject to additional filtering or signal processing after recording. Mean correlation coefficients were then calculated for the brachial and leg cuff data, and for brachial and forearm cuff data.

Results

Polygraph test data from field examination is often observed to be of varying quality. The interpretable quality of cardiograph data can be impaired by several different types of data artifacts, including respiratory blood pressure fluctuation, fasciculations, physical movement, extrasystoles (ectopic heartbeats), arrhythmia, general instability, dampening and other artifacts. [Refer to Nelson (2022) for a description of common cardio artifacts during polygraph testing.] It may be expected that different deployment solutions for the cardiograph sensor may increase or decrease the robustness and vulnerability of cardiograph data to data artifacts.

Cardiograph sensor data can also exhibit a descending trend for several minutes after the initial placement and inflation. This common observation is thought by field polygraph examiners to be possibly due to conformation, when pressurized during data recording, of the elastic and textile materials used to construct the cardiograph sensor. This effect can be mitigated by careful procedures during deployment and is often reduced after the first few minutes of data recording. During field polygraph testing, the descending trend may be dissipated during the acquaintance test. Because this project involved only the acquaintance test, no opportunity for dissipation existed prior to data recording.

Visual inspection of the data for the two samples suggested they were of acceptable quality for use or interpretation, though with some variation in the ease or difficulty in working with the data for all sensor deployments. Also, differences were observed the occurrence of data artifacts for the different cardiograph sensor deployment locations. Data of good stable quality may vary differently from data of marginal or poor quality.

Perfect correlations are not expected for the different deployment locations for the cardiograph sensor. However, it can be expected that the strength of association for the data from different cuff locations may vary with data of different interpretable quality. Data of more

[3] Mean arterial pressure (MAP) is calculated as DP + 1/3PP where DP is the diastolic pressure and PP is the pulse pressure or difference between systolic and diastolic pressures (Handler, Geddes & Reicherter, 2007. According to DeMers & Wachs (2022) MAP values of 60mmHg or more are required to maintain perfusion, and reduction of MAP to below 60mmHg for extended periods of time may lead to ischemia and infarction.

stable quality may correlate more strongly for the different recording sensors, while artifacts and instability contribute to weaker associations between the different sensor solutions. For this reason, each sample was subject to a split half-analysis.

For each sample, correlations between the time-series data from the brachial and alternative cuff deployments were rank ordered and then divided into quartiles. For each sample, the lower split half consisted of quartiles 1 and 2, while the upper split-half consisted of quartiles 3 and 4. Each split half consisted of ½ of the cases for each sample. Means were then calculated separately for each sample and each split-half. Appendix C shows the plotted time-series data for the upper half (quartiles 3 and 4) of the leg cuff sample. Appendix D shows the data plots for the lower half (quartiles 1 and 2) of the leg cuff sample. Appendix E shows the plots for the upper half of the forearm cuff sample, and Appendix F shows the lower half.

Table 1 shows the Pearson correlation coefficient for each split-half of the two sample, along with the correlations of all quartiles combined for each sample. Confidence intervals were obtained using a Monte Carlo bootstrap procedure.

Table 1. Pearson correlation coefficients and [95% confidence intervals] for each split-half of the leg cuff and forearm cuff samples.

	Combined (all quartiles)	Lower half correlation (1st and 2nd quartiles)	Upper half correlation (3rd and 4th quartiles)
Brachial and leg cuff	r = .818 [.539, .971]	r = .701 [.521 .815]	r = .936 [.863 .973]
Brachial and forearm cuff	r = .852 [.561 .985]	r = .734 [.549 .903]	r = .969 [.955 .989]

To further understand the influence of the cardiograph sensor deployment on the data quality, data artifacts were coded by the second author for all cases, including respiratory blood pressure fluctuation, physical movements, fasciculations, general instability, extrasystoles, cardio-arrhythmia, and cardio-dampening. A frequency table of artifacts is shown for each sample in Appendix B. Table 2 shows the bootstrap means and the 95% confidence intervals, obtained using a Monte Carlo bootstrap, for the number of cases for which different types of cardio artifacts were observed. These intervals are an estimate of the range of proportions, based on the observed data, for which other cases may be expected to exhibit these cardio artifacts. Cardio arrhythmia and cardio-dampening were not observed in either of the two samples but were estimated at the .005 value.

Table 2. Mean and [95% CI] for the frequencies of observed cardio data artifacts

	Brachial and Leg Cuff (n=16)		Brachial and Forearm Cuff (n=16)	
	Brachial	Leg	Brachial	Forearm
RBPF (mild)	.005 [<.001, .063]	.312 [.125, .563]	.065 [<.001, .188]	.186 [<.001, .375]
RBPF (moderate to severe)	.125 [<.001, .313]	.004 [<.001, .063]	.440 [.188, .688]	.006 [<.001, .063]
Fasciculations	.064 [<.001, .188]	.062 [<.001, .188]	.004 [<.001, .063]	.004 [<.001, .063]
Physical movement	.005 [<.001, .063]	.005 [<.001, .063]	.005 [<.001, .063]	.062 [<.001, .188]
Extrasystoles	.064 [<.001, .188]	.062 [<.001, .188]	.005 [<.001, .063]	.006 [<.001, .063]
General instability	.005 [<.001, .063]	.005 [<.001, .063]	.126 [<.001, .313]	.004 [<.001, .063]
Arrhythmia	.005 [<.001, .063]	.005 [<.001, .063]	.005 [<.001, .063]	.005 [<.001, .063]
Dampened/unresponsive	.005 [<.001, .063]	.005 [<.001, .063]	.005 [<.001, .063]	.005 [<.001, .063]
Other artifact	.061 [<.001, .188]	.065 [<.001, .188]	.004 [<.001, .063]	.005 [<.001, .063]
Descending cardio data (25%)	.189 [<.001, .375]	.561 [.313, .813]	.125 [<.001, .313]	.126 [<.001, .313]

Inspection of the artifact frequencies suggests that deployment of the cardiograph sensor on the leg resulted in an increase in descending cardiograph data. Nine (9) of 16 cases in the leg cuff sample exhibited a cardio descent of 25% or more of the vertical (y-axis) graphic scale. This may be due to conformation and settling of the elastic and textile cuff materials after the cuff is pressurized and may subside after the first few minutes. Another observation is that the occurrence of moderate to severe RBPF was reduced for both alternative deployment locations, compared to the traditional brachial location.

Although the number of cases with moderate or severe respiratory fluctuation in the cardio data decreased when the cardiograph sensor was deployed on the leg and forearm, the number of cases for which a mild respiration signal was observe increased for both samples. For the purpose of coding these data, mild RPBF was defined as slight, though observable respiration pattern in the cardiograph data which was not expected to influence polygraph feature extraction or data analysis, and which could easily be ignored or overlooked.

A Kruskal-Wallis rank sum test (Hollander & Wolfe, 1999), a form of non-parametric ANOVA, was used to check the statistical distance between the frequency of occurrence of the cardiograph data artifacts shown in Table 2. This test was used because it does not assume a normal distribution, and can work with small sample sizes. With two samples it is equivalent to a Wilcoxon-Mann-Whitney test, also a non-parametric t-test, but can better tolerate the existence of tied values. Differences in the occurrence of cardiograph data artifacts were not statistically significant for deployment of the cardiograph sensor on the leg [p=.815, df=1, x^2=.052] or the forearm [p=.939, df=1, x^2=.006].

Discussion

This study involved the collection of simultaneous time-series recordings of the cardiograph data using the cardiograph sensor deployed in the traditional brachial location in addition to the leg cuff and forearm cuff deployments. Alternative solutions are desired for the traditional brachial arm cuff used in polygraphic credibility assessment testing for two main reasons: to reduce the vulnerability of the cardiograph sensor data to artifacts that may disrupt the usability of the data, and to reduce level of physical discomfort that may be experienced and reported by polygraph examinees. Data were obtained using a common form of acquaintance or practice test. Correlations were calculated for the two alternative cuff deployments. Very high correlations were observed for both sensors when the recorded data were stable and of acceptable interpretable quality.

Like all projects, this study is not without some limitations. The first limitation is that this study is limited to the polygraph context and does not involve the use of alternative cardio cuff deployments in medical use. Another limitation of this project is the small sample size. Although larger sample sizes are nearly always preferred, this small study does provide interesting information where no previous analytic information exists. A related limitation is that data for this study, like many polygraph studies, are limited to persons of normal functional characteristics in terms of both medical and mental health.

A further limitation of this project is that data for this study involved only the acquaintance test and does not include data from comparison question test charts. Although it may be tempting to speculate about whether meaningful differences will be observed between the cardiograph sensor correlations of acquaintance test data and comparison question data, such speculation is presently without supporting evidence as to any actual differences and why such differences might exist. Although the present correlation study indicates a very high correlation, for polygraph time-series data, between the cardiograph cuff deployment in different locations, future research should endeavor to evaluate polygraph outcome effect sizes using the forearm-cuff solution.

Some anecdotal observations were made during data collection for this study. It was observed that achieving stable data may be more difficult with the leg cuff than with the brachial and forearm cuffs. There were more observed cases in which the leg cuff data descended more than 25% of the graphical y-axis during the acquaintance test exercise. This descending pattern can be the result of conformation of the elastic and textile cuff materials when pressurized. The descending trend in the data usually dissipates after a few minutes of time. In practical terms, this may indicate that effective deployment of the cardiograph cuff on the leg may be more complex or difficult.

Deployment of the cardiograph sensor requires intrusion of the examiner into the personal space of the examinee and requires some physical contact with the examinee. The forearm deployment in the personal proxemic zone (Hall, 1969) – about 18 to 48 inches surrounding a person – may provide more comfortable opportunity for examiners to work the cuff to a point of stability prior to data recording. In contrast, the brachial arm cuff may be considered closer to the intimate zone – the space less than 18 inches around a person. Deployment of the cardiograph sensor on the lower leg introduces the potential for additional social and personal difficulties when the examiner bends down in front of the examinee's legs, and this may contribute to ineffective deployment and an increased occurrence of descending data during the early minutes of data collection.

A not-unexpected observation was that examinees reported less physical discomfort from the deployment of the cardiograph sensor on the forearm and leg, compared the traditional brachial arm cuff. Causing other physical discomfort to other persons is a potential source of ethical controversy, even during professional interactions, and is therefore not without some need for discussion. Controversy of this type may be reduced when alternatives exist that contribute to less discomfort. Commensurately, the use of methods that contribute to physical discomfort may be viewed as more ethically questionable when viable alternatives exist. No subjective or objective data was captured in attempt to quantify the level of physical discomfort experienced by the examinees with any of the deployment solutions used in this project.

Other anecdotal observations were made. A potentially useful observation was that respiratory blood pressure fluctuation, a common involuntary condition which may complicate data analysis, may sometimes be reduced by simple strategies such as elevating the forearm, straightening the arm, and deploying the cardiograph cuff on the smaller part of the forearm above the wrist. A final observation was that deployment of the cardiograph cuff on the forearm was easier in some ways than the traditional brachial location – despite the fact that deployment of the cardiograph sensor on the forearm with persons with small sized forearms required more wrapping of the textile part of the sensor. Deployment on the forearm may become easier with the use of a cardiograph sensor that is sized more optimally for the forearm location. A final anecdotal observation was that conducting the examination with less physical discomfort may contribute to improved attention to the test stimuli and improved signal quality.

Replacement of a recording sensor solution that is supported by decades of validity research, published statistical models, and exhaustive field experience is a complex task. A convenient or ideal solution will be a replacement sensor solution in the form of a drop-in replacement that provides a very high correlation with the replaced sensor when data are of normal, un-artifacted, interpretable quality, while increasing the number of cases for which the cardiograph sensor data will remain usable. In this project, very high correlations were observed between two alternative deployment locations for the cardiograph sensor – the lower leg and the forearm. Correlations were weaker when data from one of the sensors was descending more than the other during recording, and when data was unstable. Correlations were stronger when data from both sensors were stable and when data from both sensors were descending. These results suggest that field examiners should take care to ensure the stability and usability of cardiograph sensor data prior to recording onset.

Results from this study suggest that two alternative cardiograph sensor deployment solutions, leg cuff and forearm cuff, may be suitable for drop-in use, and may provide some advantages in terms of improved data quality. However, concerns about thrombosis, a serious medical event, however, rare, should preclude further interest in the use of the leg cuff deployment. There may be ethical discussion around the use of a solution that increases medical risk when options exist with less medical risk and which may be similarly or potentially more effective. Replication of this study, and continued interest in the forearm cuff deployment are recommended.

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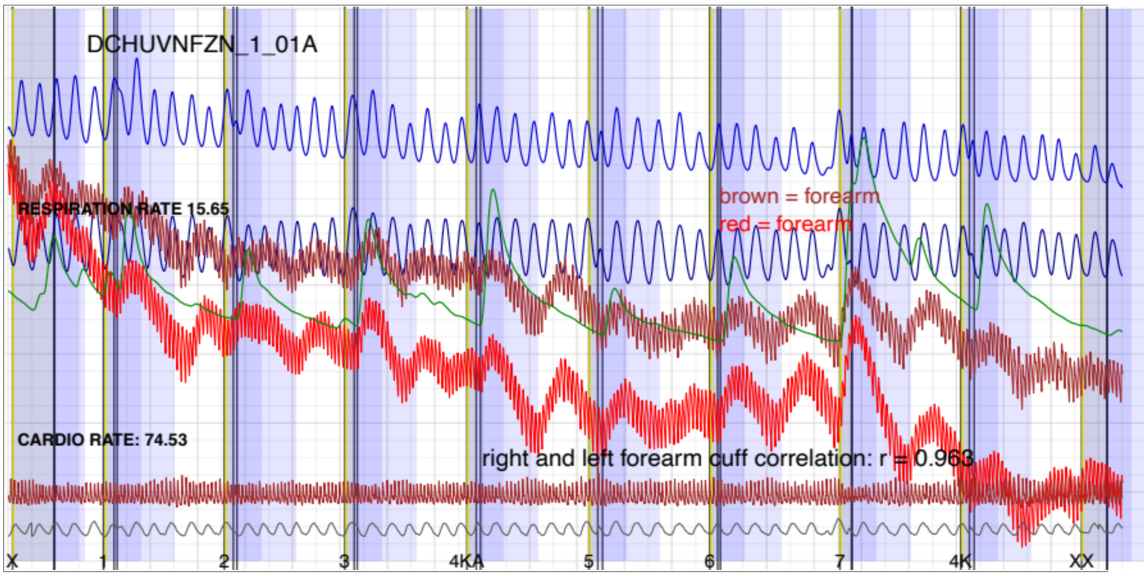
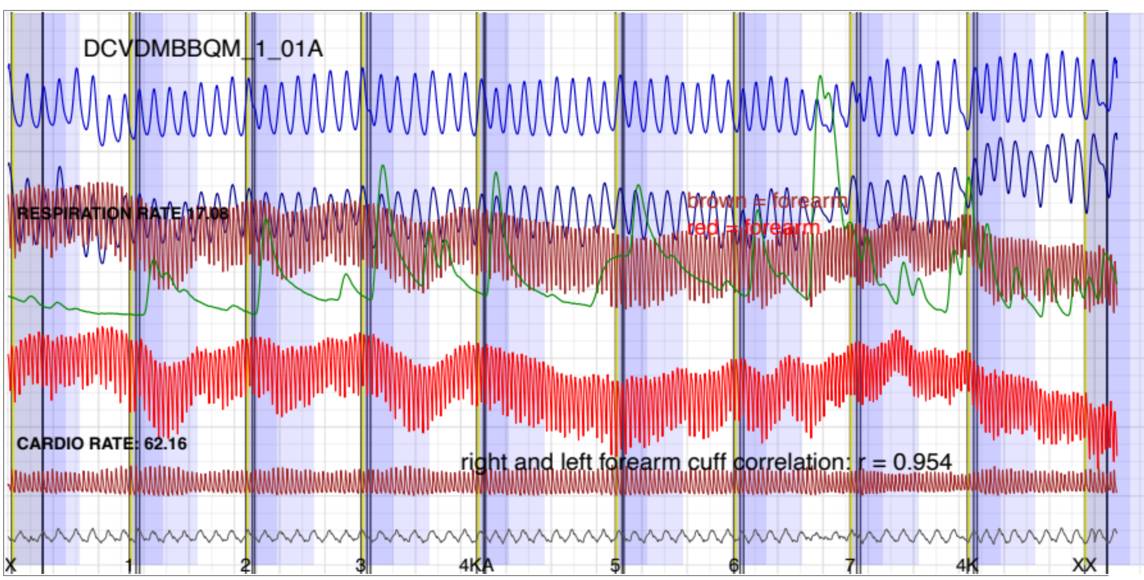
Appendix A
Graphic Plots for Two Forearm Cuffs

Mean correlation r = .959





Appendix B
Artifact Codes for Leg and Forearm Cuff Data

Table B-1 – Observed artifacts for brachial and leg cuff data. (B = brachial arm cuff, L = leg cuff)

Case	RBPF (mild)	RBPF (mod/sev)	Fasciculation	Phys Mvt	Extrasystole	General Instability	Arrythmia	Unresponse	Other	Descending
OGSGRVTB										B L
TVEHYBQK										B L
BDWEALAD	L								B L	B L
UDFXDVVH										
AOSJYJBX		B								
OHOCSBEB	L		L							L
ZPEGMBHY										L
JMMXNYDT		B	B							L
NBDUSTSY					B L					
KXQPLAOF	L									
WTYOQNQL										
QTXIDVHL	L									L
RRFZYFVS	L									L
WUUCRKKB										
ROTUIIXT										
VHYUQLXN										L

Table B-2 – Observed artifacts for brachial and forearm cuff data. (B = brachial arm cuff, F = forearm cuff)

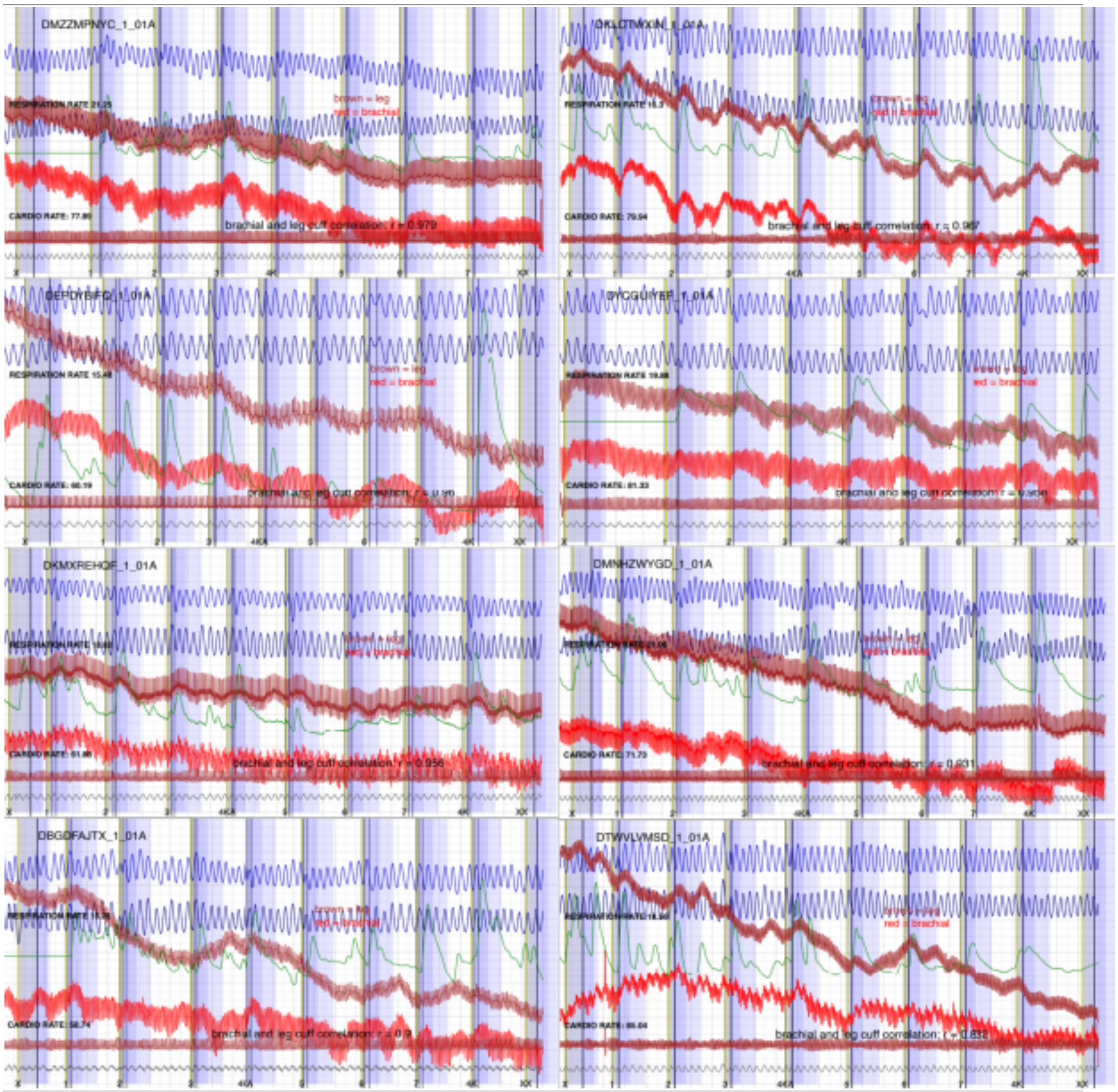
Case	RBPF (mild)	RBPF (mod/sev)	Fasciculation	Phys Mvt	Extrasystole	General Instability	Arrythmia	Unresponse	Other	Descending
MZZMPNYC										B F
KLCTWXIN										B
EPDYBIFQ										
YCGUIYEF		B								B
KMXREHQF										
MNHZWYGD										
BGDFAJTX		B								B F
TWVLVMSD	F	B								
YMITRQYP	B F									
QLTSJOBX										
XTPCIBJD										
MNSIGFCN	F	B				B				
JGTBVRYE		B								B
XNXXJEBE		B								B
QETHLJDC		B		F		B				
JSJWOJEU										

Table B-3. Frequency of cases with observed cardio artifacts, and [95% CI]

	Brachial and Leg Cuff (n=16)		Brachial and Forearm Cuff (n=16)	
	Brachial	Leg	Brachial	Forearm
RBPF (mild)	0	5	1	3
RBPF (moderate to severe)	2	0	7	0
Fasciculations	1	1	0	0
Physical movement	0	0	0	1
Extrasystoles	1	1	0	0
General instability	0	0	2	0
Arrhythmia	0	0	0	0
Dampened/unresponsive	0	0	0	0
Other artifact	1	1	0	0
Descending cardio data (25%)	3	9	2	2

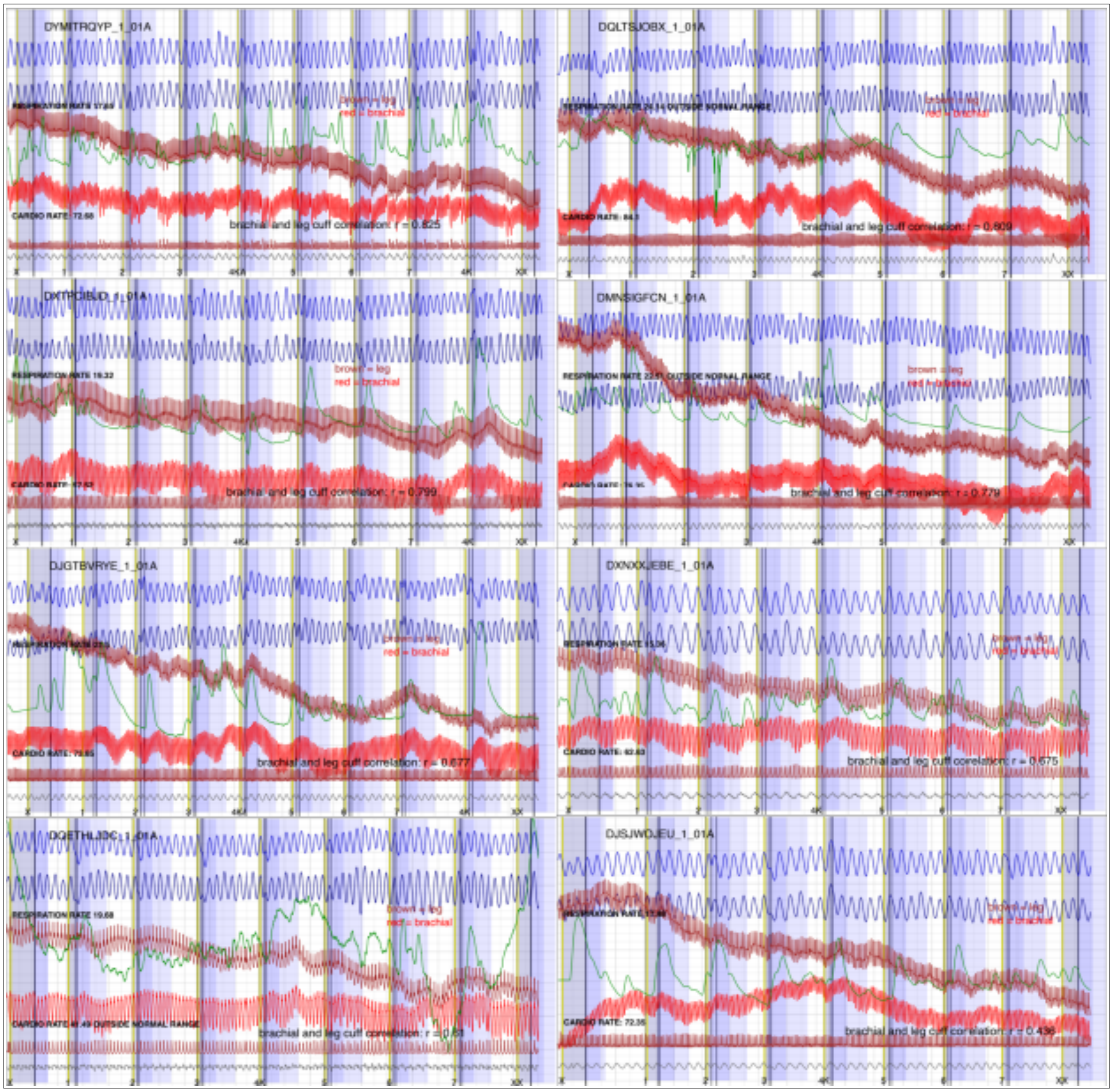
Appendix C
Graphic Plots for Brachial and Leg Cuff Data: Upper Half (3rd and 4th Quartiles)

```
an(corDAT[rev(order(corDAT))][1:8])
[1] 0.9355954
```



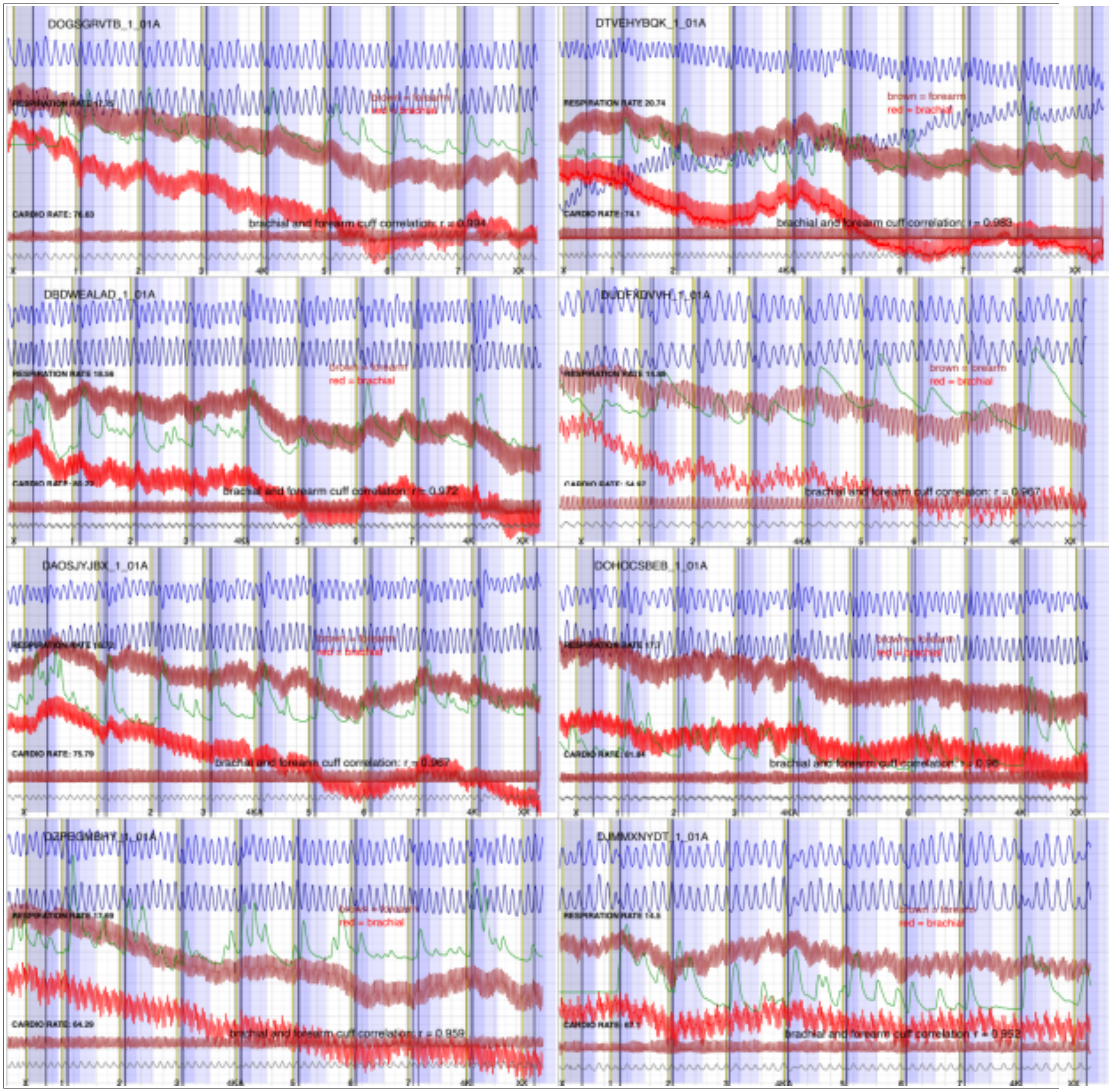
Appendix D
Graphic Plots for Brachial and Leg Cuff Data: Lower Half(1st and 2nd Quartiles)

```
mean(corDAT[rev(order(corDAT))][9:16])
# [1] 0.7013204
```



Appendix E
Graphic Plots for Brachial and Forearm Cuff Data: (3rd and 4th Quartiles)

```
mean(corDAT[rev(order(corDAT))][1:8])
# [1] 0.9692815
```



Appendix F
Graphic Plots for Brachial and Forearm Cuff Data: Lower Half
(1st and 2nd Quartiles)

```
mean(corDAT[rev(order(corDAT))][9:16])
# [1] 0.733963
```