BRIEF REPORT

ACHIEVING COLLECTIVE COHERENCE: GROUP EFFECTS ON HEART RATE VARIABILITY COHERENCE AND HEART RHYTHM SYNCHRONIZATION

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Objectives • This study examined whether a group of participants trained in achieving high states of heart rate variability coherence (HRVC) could facilitate higher levels of HRVC in an untrained subject in close proximity.

Design • Fifteen adult volunteers were trained to increase their HRVC. In a series of 148 10-minute trials using six different experimental protocols, three of the trained participants were placed together with one of 25 additional volunteers to test whether the three could collectively facilitate higher levels of HRVC in the fourth.

Results • The HRVC of the untrained subject was found to be higher in approximately half of all matched comparisons and was highest in cases where all four participants focused on achieving increased HRVC. A probit analysis revealed a statistical relationship between participants' comfort with each other and trial success. Greater levels of inter-group comfort were seen to be positively linked to increases in HRVC. Evidence of heart rhythm synchronization between group members was revealed through several methods, including correlation analysis, coherence analysis, wavelet coherence analysis, and Granger causality tests. Higher levels of HRVC were found to be correlated with higher levels of heart rate synchronization between participants.

Conclusions • These results suggest that a coherent energy field can be generated and/or enhanced by the intentions of small groups of participants trained to send coherence-facilitating intentions to a target receiver. This field is made more coherent with greater levels of comfort between group members. The evidence of heart rhythm synchronization across participants supports the possibility of heart-to-heart bio-communications. (*Altern Ther Health Med*. 2010;16(4):62-72).

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In some studies related to decision-making, it has been suggested that an energetic pathway for communications is formed between two objects that share the same resonance frequency.[1,2] In sports, when a top team is playing at its best, it often seems as though its members are communicating on a level beyond that of spoken words, orchestrated by a form of collective coherence. Is there a pathway connecting a group's members that facilitates greater interpersonal understanding and group coordination? If so, what governs these exchanges, and can they be measured?

Dr Eric Leskowitz, a Boston psychiatrist, has suggested that participants skilled in achieving high levels of heart rate variability coherence (HRVC) might be able to facilitate the achievement of high levels of HRVC in a non-skilled subject.[3] He based this proposition on the results of a case he conducted at the Institute of HeartMath (IHM) wherein he was able to achieve high levels of HRVC when aided by several IHM staff members who were experts in achieving their own high levels of HRVC. Leskowitz hypothesised that a "facilitative field" of coherent energy was created and that this field enabled him to achieve high coherence. It was not possible to draw any conclusions from this case as it was only a single trial and had no controls. This current study examines whether groups trained to achieve high states of HRVC could facilitate increased levels of HRVC in an untrained subject. Underlying this question was an even more fundamental one: can hearts, human or otherwise, synchronize their rhythms without being in physical contact? And, if so, could heart rate synchronization be facilitated by one or more members in a group, increasing their own HRVC? If this were to be the case, it would certainly lend credence to Leskowitz's proposition while also providing evidence of a heart-to-heart bio-communication mechanism at work. More importantly, if we could understand how collective coherence is brought about then perhaps we could improve the coherence of those around us and extend coherence to a larger community.

METHOD

A group of 15 school teachers and administrators from the International School of Singapore were trained over a period of 8 weeks to achieve high levels of HRVC using the Quick Coherence Technique (QCT) developed by IHM.[4] An additional pool of 15 educators served as non-trained participants. In a series of 148

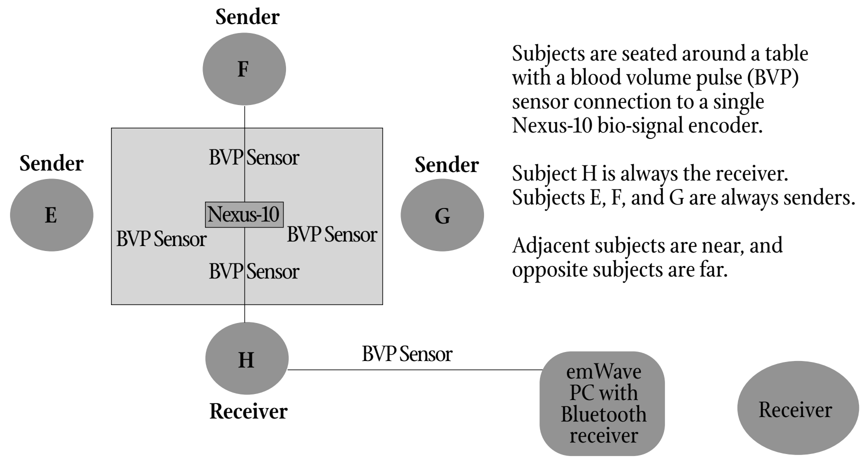


FIGURE 1 Subject Seating Arrangements and Equipment Configuration

10-minute trials, three trained participants (senders) were instructed to facilitate the HRVC of a non-trained subject (receiver) seated in close proximity. Each participant's heart rate was monitored via separate blood volume pulse (BVP) sensors connected to a single Nexus-10 bio-encoder. Though a heart rate is usually derived from an electrocardiogram (ECG), BVP can achieve the task with greater convenience and with little or no trade-off in precision.[5] Figure 1 shows the seating arrangement, bio-encoder channel assignment, and the equipment configuration used for each trail.

Different protocols were assigned to senders and receivers. These were provided on cue cards so that one participant would not know the instructions of the other. The untrained receivers were instructed to either

A. ACHIEVE—practice QCT as explained on the cue card and briefly demonstrated by the researcher or
B. RELAX—remain in a state of quiet relaxation.

Senders were assigned one of three protocols, either to

A. ACHIEVE—achieve a state of high HRVC with no attention directed to the receiver,
B. SEND—achieve high HRVC with care and compassion–infused facilitation directed toward the receiver, or to
C. RELAX—sit quietly with no attention directed to the receiver.

Together, these protocols formed six experimental conditions:

1. Sender SEND and receiver ACHIEVE (SND:ACH)
2. Sender SEND and receiver RELAX (SND:RLX)
3. Sender ACHIEVE and receiver ACHIEVE (ACH:ACH)
4. Sender ACHIEVE and receiver RELAX (ACH:RLX)
5. Sender RELAX and receiver ACHIEVE (RLX:ACH)
6. Sender RELAX and receiver RELAX (RLX:RLX)

Each trial employed one of these six experimental protocols to test whether the receiver's HRVC would increase as a result of the sender's intentions. The six protocols for senders and receivers were counterbalanced across trials to control for possible order effects.

There are a multitude of techniques for analyzing heart rate variability. The present study examined heart rate variability in both the time and frequency domains.[6,7] Time domain measures included heart rate and inter-beat intervals, and both Fourier and wavelet transform-based nonparametric methods were used to analyze the spectral characteristics of the time series data. The principal measure of HRVC reported in this article is derived from a proprietary algorithm developed by IHM that approximates the ratio of the total power in the low-frequency (LF) range of the heart rhythm to the combined power of the very low-frequency (VLF) and high-frequency (HF) ranges, or LF/(VLF + HF).[8]

In addition to the more traditional ways of analyzing heart rates, several customized techniques were adopted from other research fields. For example, a MATLAB (The MathWorks, Inc, Natick, Massachusetts) routine originally developed for analyzing relationships between geophysical time series data was customized for transforming heart rate time series into continuous wavelet transforms (CWT) and for analyzing relationships between individual heart rate time series through cross wavelet transforms (XWT) and wavelet coherence (WTC) tests of significance.[9] Another MATLAB routine originally developed for use in determining causal relationships in neural populations was used for conducting a Granger causality analysis between heart rate rhythms of multiple pairs of subjects (Figure 1).[10]

RESULTS

Table 1 shows the effectiveness of the QCT in significantly increasing levels of HRVC. Significant gains in HRVC were posted by senders and receivers alike when practicing the QCT. Overall,

TABLE 1 Mean Heart Rate Variability Coherence of Participants Using Quick Coherence Technique (QCT) compared to the RELAX Mode

		Mean HRVC Score	
Participant Group		**QCT**	**RELAX**
Receivers	Mean	0.47*	-0.13
	Standard deviation	0.66	0.65
Senders	Mean	0.66*	0.06
	Standard deviation	0.54	0.41
All Participants	Mean	0.56*	-0.05
	Standard deviation	0.61	0.55

HRVC were computed by the IHM and have been normalized. Sender's SND mode results combined with ACH mode as both utilize the Quick Coherence Technique. *Significant at $P = .05$ (t-statistic = 2.74 and 3.73, respectively) and for all subjects as a whole (t-statistic = 3.07).

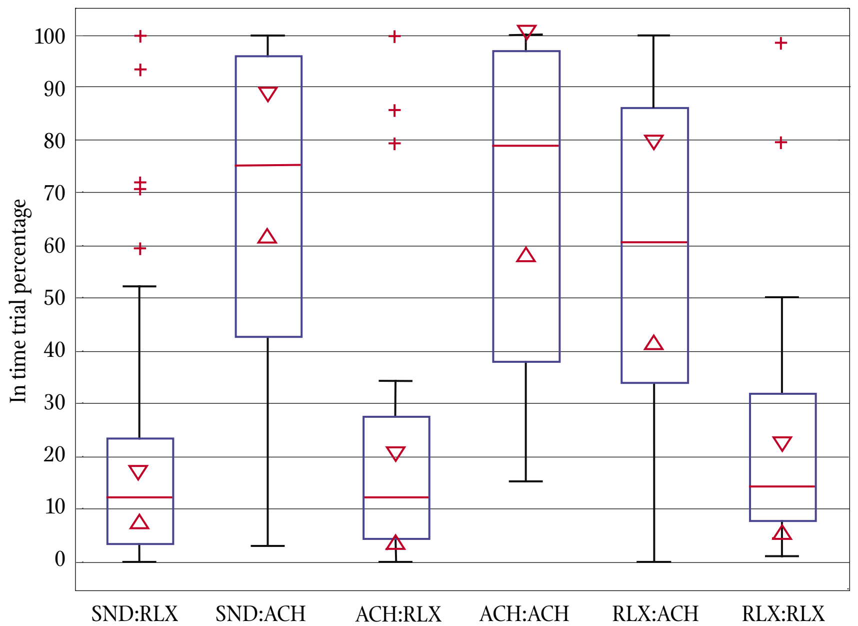


FIGURE 2 Percentage of Trial Time Receiver was in High HRVC

All of the box plots in this study were produced by MATLAB and each has the following features:

- The tops and bottoms of each "box" are the 25th and 75th percentiles of the samples, respectively. The distance between the tops and bottoms is the interquartile range (the middle 50% of the distribution).
- Comparison interval endpoints are represented as triangular markers. Two medians are considered to be significantly different at the 5% significance level if their intervals do not overlap.
- The line in the middle of each box is the sample median. The measure of the distributions symmetry, or skew, is shown by the extent that the median is not centred in the box.
- The whisker lines extending above and below each box are drawn from the ends of the interquartile ranges to the furthest observations within the whisker length.
- Observations beyond the whisker length are marked as outliers. By default, an outlier is a value that is more than 1.5 times the interquartile range away from the top or bottom of the box. Outliers are displayed with a + sign.

no significant difference was found between the HRVC levels attained by the novice practitioners (receivers) compared to those of their more experienced counterparts (senders).

As was hypothesized, receiver HRVC was found to increase when facilitated by senders. This was seen in a variety of forms. First, consider Figure 2, which shows a box plot of the percentage of trial time receivers were in a state of high coherence by experimental mode. Note here that "high coherence" in this context is determined and reported by the IHM algorithm built into the emWave PC set at Challenge Level = 1. As can be seen, receivers spent about 80% of the 10-minute trial time in high coherence while the senders were in either a SEND or ACHIEVE mode. When senders were merely relaxing, this percentage fell to 60%. In addition, the mean level of receiver HRVC in the SND:RLX condition was found to be more than twice as high as that in RLX:RLX and significantly higher than that in the ACH:RLX mode.

Figure 3 shows the distribution of receiver HRVC scores by experimental condition. Here too it is clearly seen that receivers were able to establish relatively high levels of HRVC, regardless of senders' activity. This is quite remarkable given that untrained subjects typically have difficulty sustaining or even achieving high HRVC on their first attempt. The fact that participants in this particular study had, in many instances, some prior working relationships with each other may have led to the greater ability of receivers to achieve high HRVC, and possible influencing factors are discussed below.

There is wide variability in the receivers' ability to achieve high HRVC (Figure 3), which makes it difficult for significant differences to be established. To control for variability in HRVC results across participants, a matched comparison analysis was conducted using only those cases that had the same (matched) participants. There were 55 pairs of such cases. It was found that nearly half (47.3%) of all of these met the expectation posited by the alternative hypothesis: that senders in a coherence-inducing mode (either ACHIEVE or SEND) can effect a positive difference on HRVC scores of receivers.

A probit regression analysis was conducted to help identify the factors that differentiated between whether the experimental results supported or contradicted the hypothesis that senders could positively affect receiver HRVC. The probit link function can be used in regression analysis in situations where the dependent variable is binary, as in this instance, where there are only two possible outcomes: success and failure.[11] Matched cases were classified as a success if the receiver HRVC was found to be higher when senders were in a coherence-facilitating state (SEND or ACHIEVE) vs a non–coherence-facilitating state (RELAX) and classified as a failure otherwise.

The results of a probit regression can be interpreted as the probability of success given a set of explanatory, or predictor, values.[12] In addition to heart rate and experimental mode, the predictor values considered included measures of how participants felt about each other, such as the following.

A measure of how the receiver felt toward the senders. Each participant was asked to rate the state of their interpersonal relationship (IPR) with each other trial participant using a 10-point Likert scale. It was thought that receivers may be more "signal receptive" toward people they feel good about, eg, more prone to achieve higher HRVC with people they liked.

A measure of the group's overall comfortability and friendliness. The sum of all interpersonal ratings between participants within a trial (SUM_IPR) was used to reflect the overall feeling of personal closeness between the participants, higher levels of which were believed to be more conducive to attaining higher levels of receiver HRVC.

Two measures of how the senders felt about themselves: their sense of coherence (SOC) and their lack of feelings of loneliness. SOC was measured using the SOC-13 developed by Antonovsky, while loneliness was measured using the UCLA-10.[13,14] People with a greater sense of coherence are thought to be more comfortable to be with than a person with a lesser sense of coherence, and people who feel less lonely are believed to relate better with others in general. Incidentally, researchers in Japan have shown a positive relationship between SOC-13 and heart rate variability.[15]

The resulting probit model correctly predicted the actual results in 85 out of 110 cases, yielding an overall predictive success rate of 78.2%, with all of these predictor values proving to be significant. A fuller examination of these probit results is given below. Before that, some other significant results using the correlation analysis methods are presented.

Correlation is a measure of the extent to which two data sets move in synchrony.[16] A Pearson-product moment correlation analysis revealed that about one out of three inter-subject heart rate correlations were significantly different from zero as can be seen in Figure 4. Given the large number of observations (2400 in a 10-minute time series) a correlation coefficient of greater than .063 or less than -.062 is considered significantly different than zero at $P < .05$. Within each trial there exist six inter-subject pairings, netting a total of 870 paired-subject observations across all trials. Of these, 236 pairs (27.2%) recorded a non-zero, positive correlation between the heart rhythms of the two subject pairs ($r > .062$). In addition, about one in 10 subject pairs (10.7%) were found to have a

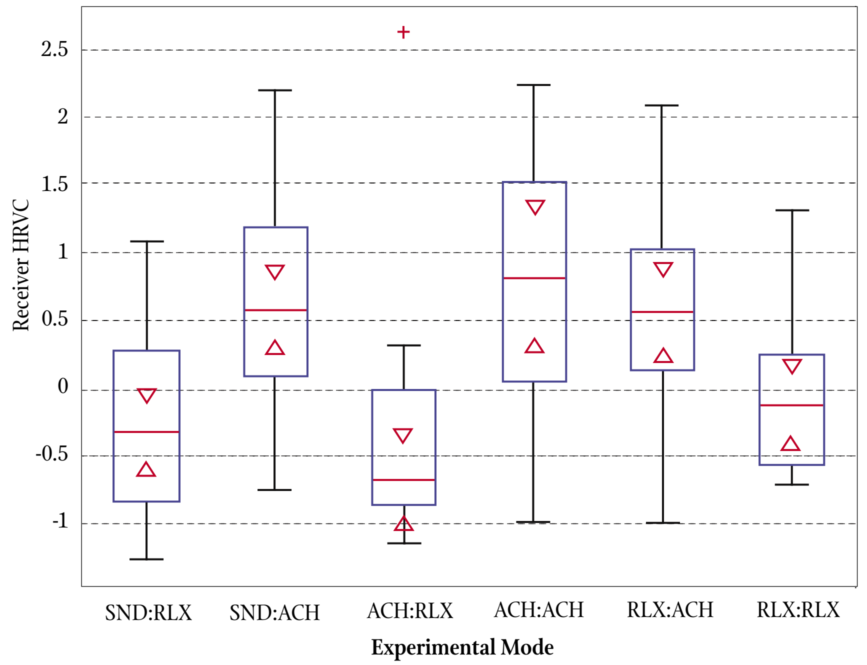


FIGURE 3 Receiver Heart Rate Variability Coherence by Experimental Mode

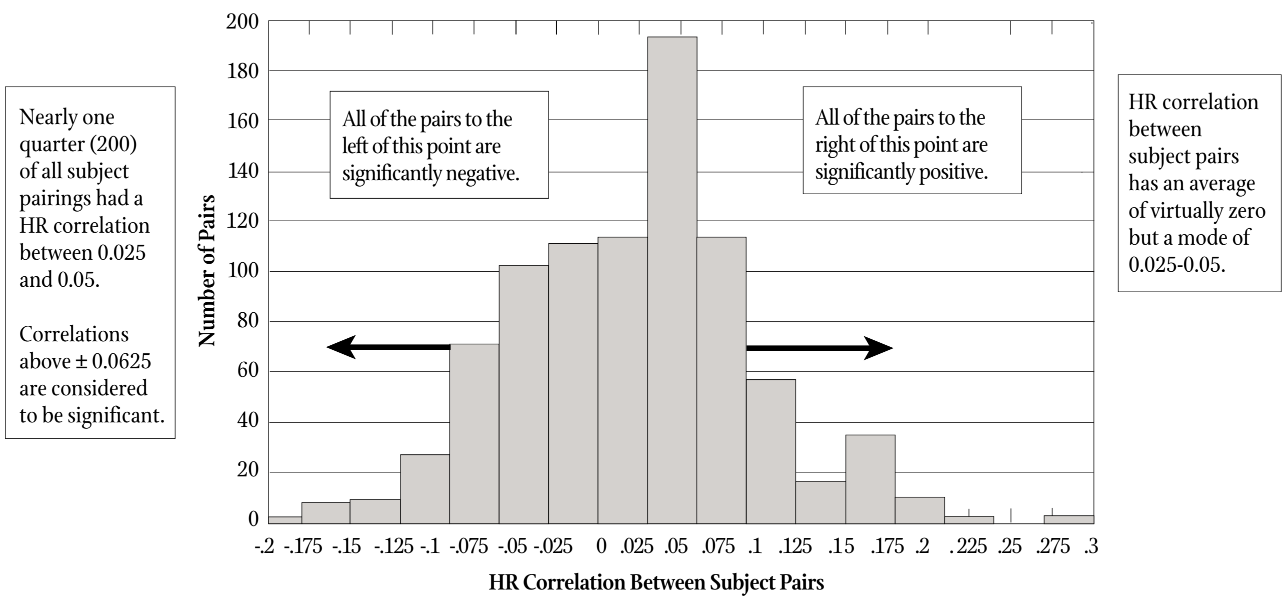


FIGURE 4 Distribution of Heart Rhythm Correlations Between Subject Pairs

significantly negative correlation ($r < -.062$). In total, more than one in three pairs (37.9%) posted a correlation statistically significant from zero. The maximum negative correlation over a 10-minute trail was -.30, and the maximum positive correlation was .45. Overall, the mean correlation of all 870 pairs was not found to be significantly different than zero. This does not, however, mean that there is no correlation between heart rates, but only that the average correlation tends to be zero over time. Since synchronization can be either in-phase (image) or anti-phase (mirror image), heart rates can be either negatively correlated or positively correlated and still be considered "in sync." The use of session statistics such as a correlation coefficient may mask over the evidence of synchronization, as the periods of in-phase and anti-phase correlation will cancel each other out. This phenomenon can be readily seen in the tracings of heart rate correlation time series between participants across a 10-minute trial, as is shown in Figure 5.

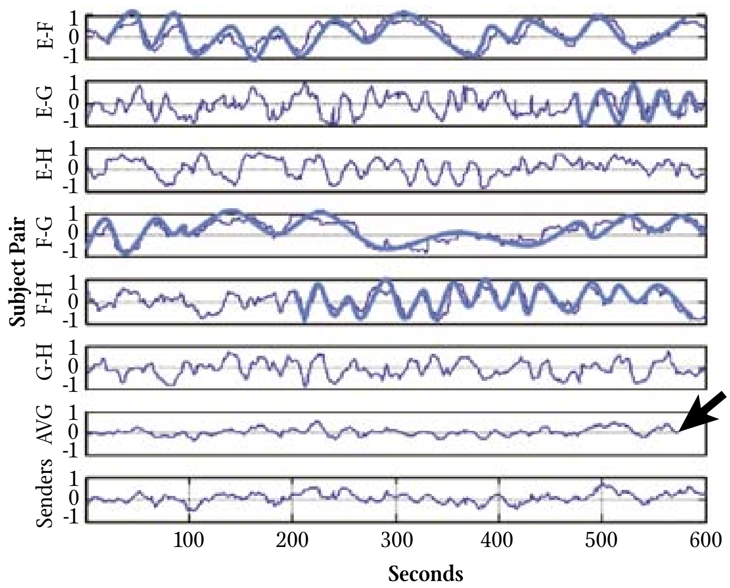


FIGURE 5 Oscillations of Heart Rhythm Correlations Between Subject Pairs

As can be seen in Figure 5, over time two heart rates can, and indeed will, move in and out of both periods of in-phase and anti-phase correlation, and, of course, they will also display periods of no correlation as well. Many such periods, or epochs, of correlation were observed throughout all 870 pairs of heart rate time series. These correlations were often seen to oscillate with periods ranging from seconds to minutes, similar to those seen in Figure 5.

To better capture the extent of both positive and negative correlation, correlation coefficients were squared to produce a coefficient of determination, or r^2. The coefficient of determination is a measure of the strength of the linear relationship between two variables. Coefficients of determinations were averaged across each of the six inter-subject pairs in a trial to form an average coefficient of determination value for that trial. Mean values of the trial average coefficient of determination ranged from .11 to .14 for a 10-minute trial (Table 2). The maximum session coefficient of determination was .23, which corresponds to an absolute value of a correlation coefficient of nearly .5. All of these results were significantly greater than zero at $P < .05$.

The ACHIEVE mode was found to facilitate the greatest extent of heart rate correlation as measured through the coefficient of determination. This was found to be true in the case of both mean and median values (Figure 6). The highest average coefficient of determination was found in cases in which all participants were instructed to follow a coherence-inducing protocol (SND:ACH and ACH:ACH modes). The coefficients of determination for both of these modes were found to be statistically higher than those in the ACH:RLX, RLX:ACH, and RLX:RLX modes.

The median value of the coefficient of determination within a

TABLE 2 Coefficient of Determination (r^2) Between Heart Rate Time-Series Across All Subject Pairs Within a Single Trial by Experimental Mode

	Mode					
	SND:RLX	SND:ACH	ACH:RLX	ACH:ACH	RLS:ACH	RLX:RLX
Mean	.128	.140	.121	.142	.106	.111
Median	.126	.139	.115	.137	.102	.104
Min	.095	.096	.087	.095	.081	.072
Max	.195	.227	.169	.193	.171	.191
SD	.025	.027	.027	.026	.020	.033

Data are averaged across six session pairings across all 10-minute trials. All means are significantly greater than zero at $P = .05$.

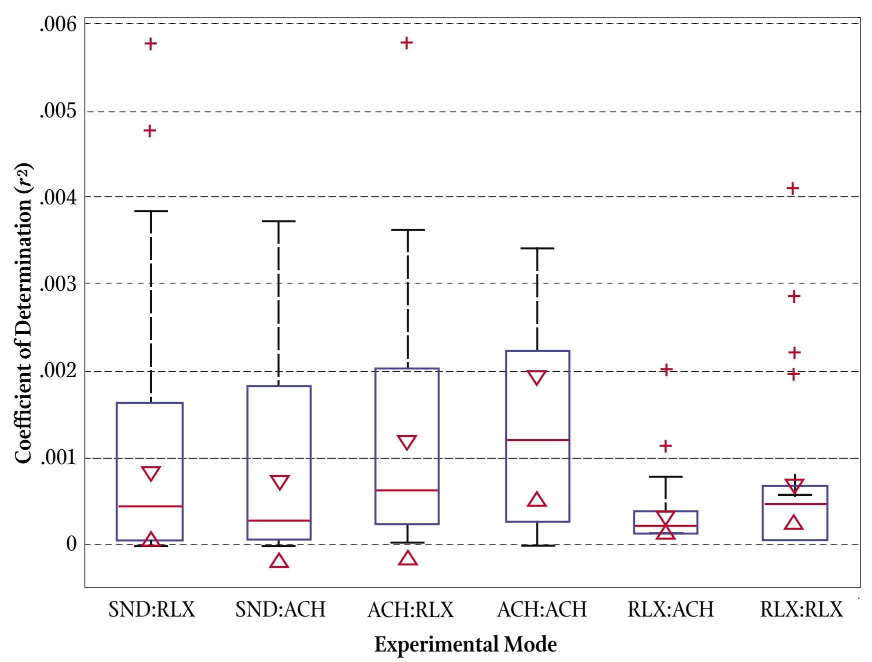


FIGURE 6 Median Coefficient of Determination (r^2) between Subject Heart Rates by Mode

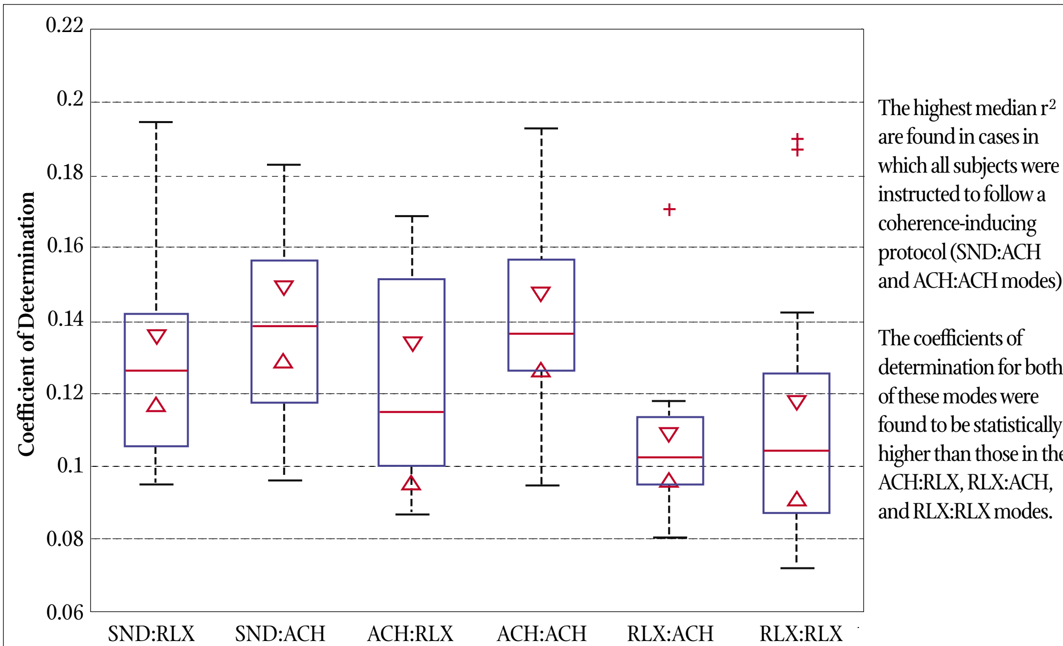


FIGURE 7 Mean of Average Coefficient of Determination between Participants by Mode

trial was found to be slightly positive, ranging from .02 to .012 (Figure 7). This was most prevalent in the case of ACH:ACH, which posted a median r^2 significantly more positive than the median r^2 of the RLX:ACH trials, meaning that senders, while in ACHIEVE mode in conjunction with a receiver who is also in ACHIEVE mode, will likely post a higher median correlation in heart rate time series than when they (senders) are in RELAX mode, regardless of receiver mode. Simply put, heart rhythm correlation within a group is highest when senders are in a coherence-inducing mode.

Across all modes and across all participants, the session coefficient of determination was found to be zero, again suggesting that heart rate time series between people are not linearly correlated over time in general. However, as was shown within segments of time, heart rhythms can and often will be highly correlated. Furthermore, heart rhythm correlations were seen to change over time and with varying periods; hence, heart rhythms between people are best considered to be dynamically correlated.

For a better view of this dynamic relationship, wavelet techniques were employed to find regions in time frequency space where the heart rate time series between participants covaried. Continuous wavelet transforms (CWT) were used to expand the heart rate time series into a time frequency space where oscillations can be seen in a highly intuitive way (Figure 8). The idea behind the CWT is to stretch a band pass filter (wavelet) in time by varying its scale and normalizing it to have unit energy.[9] Note that this technique will create edge artifacts in the data because a wavelet is not completely localized in time. The dashed-line curve in the figure is called a cone of influence (COI) and defines the area in which the wavelet power caused by a discontinuity at the edge has dropped to e^2 of the value at the edge. Another way of interpreting a COI is that it represents the region where some of the data are being interpolated rather than being calculated due to the nature of the running time window used to calculate the wavelet's value at a point in time.

The cross wavelet transform (XWT) is a complex conjugation of two individual CWTs and shows regions where the two have high common power.[9] The cross wavelet transform further reveals information about the phase relationship between two time series; in this case, between the two participants' heart rate time series. An example of an XWT is presented in Figure 9, wherein two heart rate time series are seen to share significant common power in the 8-to-16 period range (.625 - .125 Hz) throughout the 10-minute trial. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left, and one leading the other by 90 pointing straight down/up). In this example, both participants are practicing the QCT.

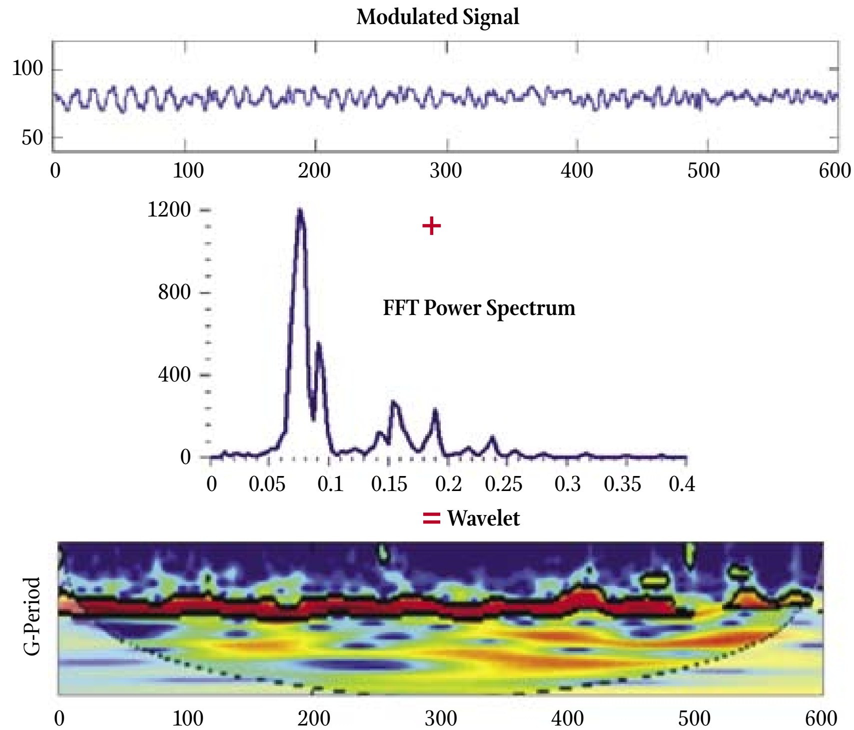
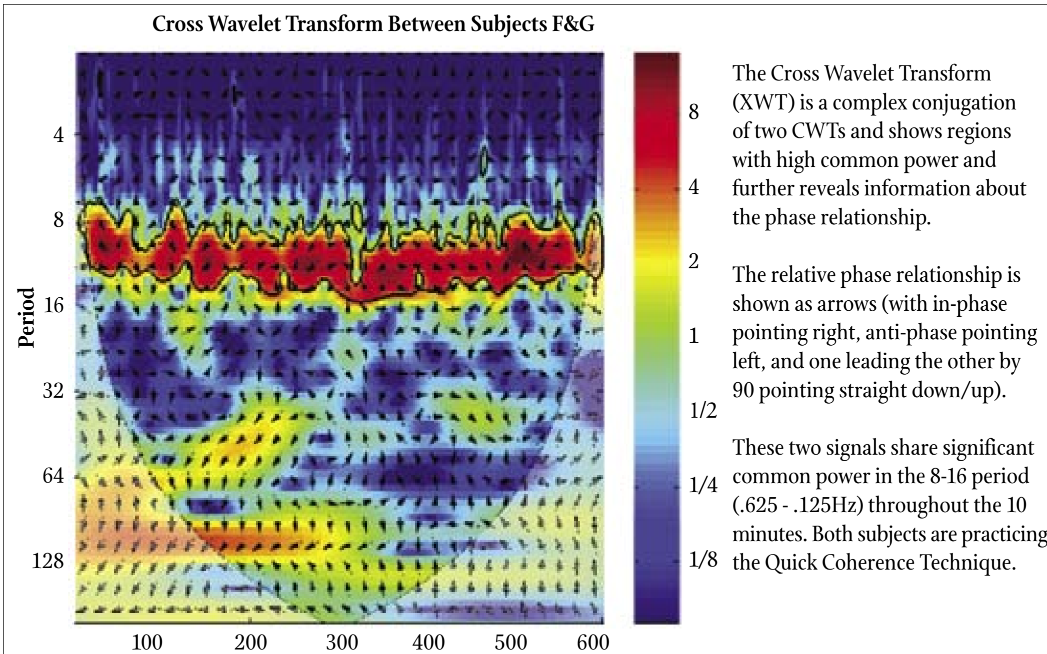


FIGURE 8 Constructing a Continuous Wavelet Transform

Coherence as a measure is an extension to Pearson's correlation coefficient and is defined as the absolute square of the cross-spectrum of two signals normalized by the product of their auto-spectra. Note here that we are describing the coherence of the heart rate time series and not heart rate variability. As was done in the case of the correlation coefficient, the wavelet coherence is squared to capture both positive and negative moments of correlation. Used in this way, squared wavelet coherence (WTC) can detect the coupling between the two heart rate signals regardless of the frequency range. It can be interpreted much like a traditional coefficient of correlation, which considers both the time and frequency domain simultaneously.



Notes: The cross wavelet transform chart above was produced by a customized MATLAB routine that was modified from one originally developed by Grinsted , Jevrejeva, & Moore.[9]

FIGURE 9 Example of a Cross Wavelet Transform Between Heart Rates of Two Participants

Using Monte Carlo simulation methods, squared wavelet coherence was used to test whether regions in time-frequency space with large common power have a consistent phase relationship, suggestive of causality between the two heart rate time series. An example of a squared wavelet coherence significance test is given in Figure 10, which reveals extremely high coherence (>.9) between the two participants' heart rates at periods 8 to 16 (.125-.0625 Hz), especially between the 300- and 400-second marks. During those 100 seconds, participant G's heart rate is seen to be leading (driving) participant F's heart rate into a period of anti-phase synchronization.

Using these dynamic correlation-testing techniques, many periods of statistically significant squared wavelet coherence were observed. The majority of these appeared in the frequency range of .07 to .13 Hz, which is the typical frequency range of high HRVC. Various examples of the squared wavelet coherence of inter-subject heart rates time series are shown in Figure 11. On the whole, the greatest periods of significant squared wavelet coherence were found when at least one member of the subject pair was in a state of high HRVC.

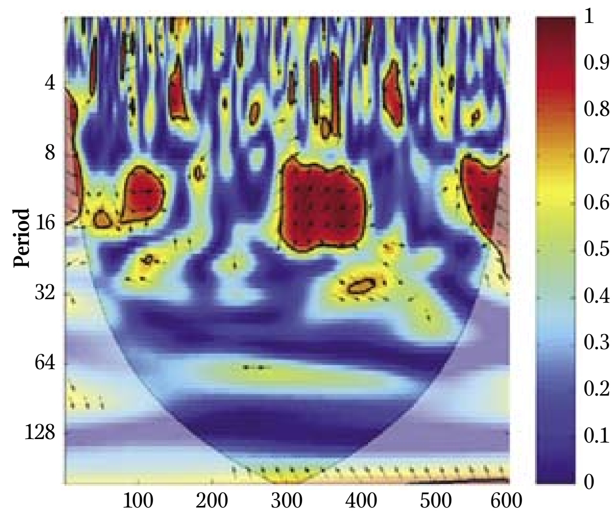
Finally, additional linkages in the inter-subject heart rate time series were revealed using Granger causality (GC) tests. A Granger causality test examines whether the lagged values of one time series can be used to reliably predict another time series—in this case, whether one participant's heart rate time series can be used to predict another person's heart rate time series. If so, the first person's heart rate is said to Granger cause the second's.[17] Granger causality is considered to be a key technique for assessing causal relations and information flow among simultaneous time series.[18-22]

Figure 12 shows a sample Granger causality test results involving four participants (E, F, G, and H) in the ACHIEVE mode. Of the 870 subject pairs with usable data in the study, 215 pairings were found to have a significant Granger causality relationship ($P < .05$), yielding an overall GC prevalence rate of about 1 out of 4 (24.7%). Under the null hypothesis of there being no GC relationship between subject pairs, random chance could account for up to 87 cases at $P = .05$. The fact that there are 215 cases is

Coherence as a measure is an extension to Pearson's correlation coefficient, and is defined as the absolute square of the cross-spectrum of two-signals normalized by the product of their auto-spectra.

Wavelet coherence (WTC) detects the coupling between the two signals, regardless of the frequency range.

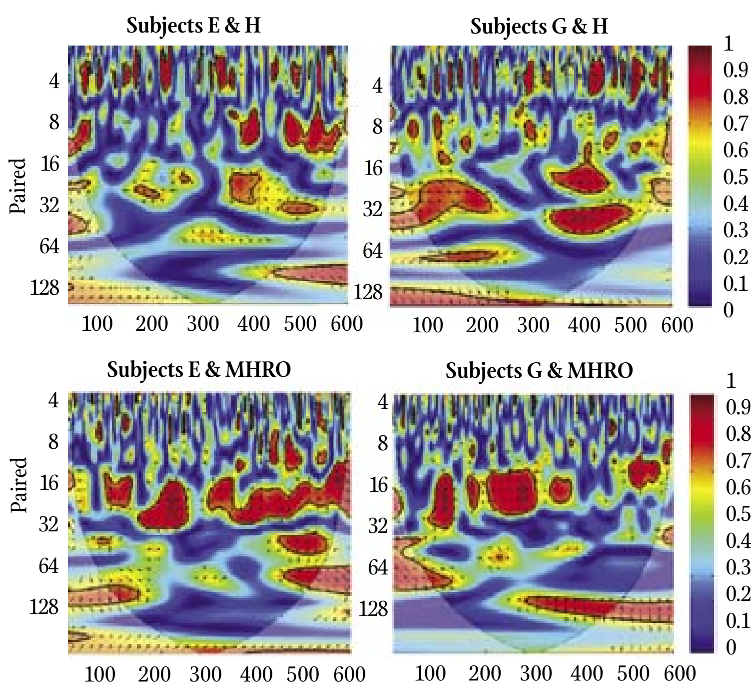
Using Monte Carlo methods, WTC can be used to test whether regions in time frequency space with large common power have consistent phase relationship, suggestive of causality between the time series.



Extremely high coherence (>.9) between two subjects at periods 8-16 (.125-.0625Hz), especially between the 300-400 second marks. Here, subject G is leading subject F into a period of anti-phase synchronization.

Notes: The Squared wavelet coherence chart above was produced by a customized MATLAB routine that was modified from one originally developed by Grinsted , Jevrejeva, & Moore.[9]

FIGURE 10 Example of Squared Wavelet Coherence Between Heart Rates of Two Participants



Each session of four subjects yields 6 heart rate pairings.

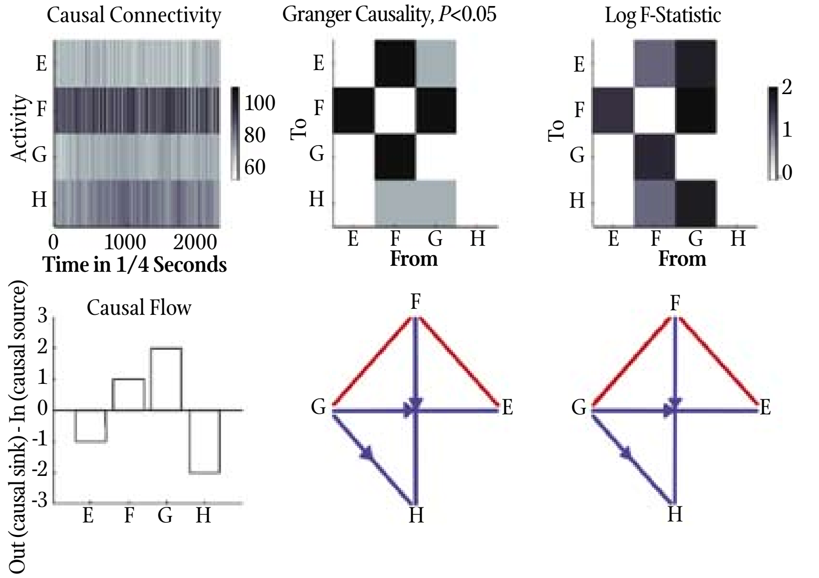
Each subject's HR was also correlated in real time with the average heart rate of the three other subjects—Mean Heart Rate Others (MHRO).

A Monte Carlo method was applied to test for significnce from random white noise at 5% level (black contours).

Notes: The Squared wavelet coherence charts above were produced by a customized MATLAB routine that was modified from one originally developed by Grinsted , Jevrejeva, & Moore.[9]

FIGURE 11 Examples of Squared Wavelet Coherence between Heart Rates of Subject Pairs

In the figure, light gray tiles are significant at $P<.05$ while the solid black tiles are significant at $P<.01$; blue lines with an arrow indicate a unidirectional relationship, and red lines without an arrow indicate a bidirectional GC relationship.



As can be seen in the figure, this trial has 7 Granger causality (GC) pairs that are significant at $P<.05$ (5 of these are significant at $P<.01$).

Subject E was in 3 of the & GC pairs; while F was in 5, G in 4 and H in 2. There are a total of 14 GC pairs in this trial, 12 unique pairs as there 2 bidirectional GC pairs.

Notes: The Granger causality charts here were produced by a customized MATLAB routine that was modified from one originally developed by Anil K. Seth.[10]

FIGURE 12 Example of Granger Causality Test of a Single Trial Involving Four Participants

clearly significant. Granger causality relationships were most prevalent among pairs that included a receiver; these recorded 115 GC cases (13.2%) compared to a critical value of 22 cases (5.0%) under the null hypothesis that there is no relationship. This is particularly interesting given that while receivers made up only 25% of the total seats in the session, their prevalence in a GC pairing is more than twice that (53.4%). Receivers were most definitely "the center of attention" in as far as the Granger causality test was concerned. Perhaps these results should come as no surprise given that senders were trying to "connect" with the receiver.

DISCUSSION

Receiver HRVC was indeed enhanced when senders were in a more coherent state themselves. However, the results were somewhat weaker when senders were attempting to facilitate the HRVC of the receiver. This suggests that trying too hard to facilitate coherence in someone else might actually be counter-productive. These results are illustrated in Figure 13, which shows the box plots of median receiver HRVC scores across the six different experimental modes.

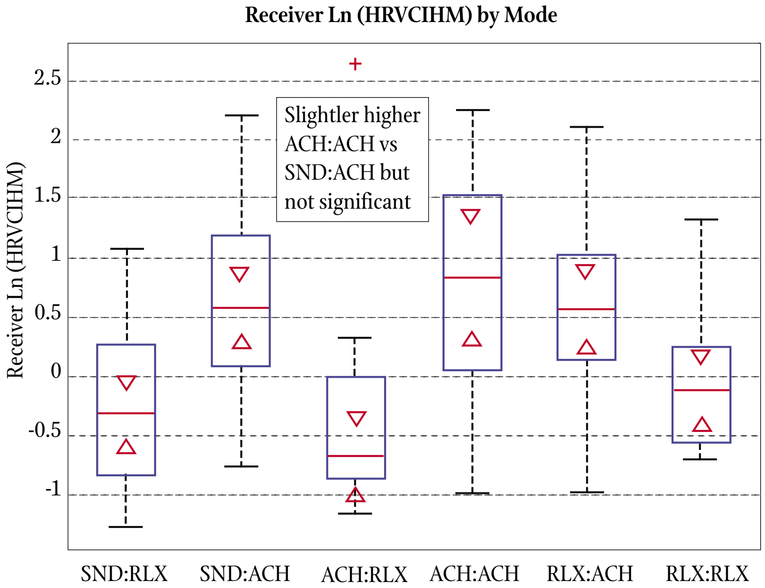
In addition, the receiver HRVC scores were seen to be highest when senders were merely relaxing while receivers were attempting to ACHIEVE coherence on their own. On the one hand, senders were seen to facilitate coherence when the receivers were in RELAX mode. Yet on the other hand, mean receiver HRVC was lower when senders were trying to facilitate it. It seems as though, in some cases, the senders and receivers may not have been working in tandem and may have even been working across purposes in as far as achieving high coherence is concerned. This was subsequently verified by post-trial interviews and in the interpersonal relationship ratings. Participants who did not share some degree of fondness toward each other were less likely to achieve coherence in a group setting.

It would seem that by having senders focus on achieving high HRVC themselves helped more in terms of raising receiver HRVC than having them attempt to facilitate receiver HRVC directly. It would appear as though the act of trying to direct facilitative energy brings in a degree of performance anxiety that may actually interfere with energetic transfers. This result alone has profound implications on efforts to induce coherence in others.

Clearly, there are other forces at work beyond sender intentions in explaining receiver HRVC score variability. For one, it would seem that the receiver's mental and emotional states matter as well, forming a psychophysiological "receptivity." While senders are attempting to "project" their facilitative energies, receivers are consciously, or more likely, unconsciously, choosing to accept or reject these energetic intentions.

The sender-receiver circuit can best be understood as a dynamic two-way channel that can be influenced at any time by either party. In the original research design it was naively assumed that senders could influence receiver HRVC unilaterally and without receiver permission. This appears not to be the case in fact, as the probit model results indicate that the quality and extent of the interpersonal relationships between participants matters more than the actions and intentions of the senders. Two implications for future research should be clear: (1) that receiver's mental and emotional condition should be a control variable as well as the sender intention and (2) that fostering strong relationships will likely foster greater levels of group and individual coherence.

The results also suggest that the quality and extent of interpersonal relationships matter when it comes to group performance—in this case, achieving high receiver HRVC. How people



Note: Heart rate variability coherence (HRVC) scores were calculated using the natural log transform of a proprietary algorithm developed by the Institute of HeartMath.[8]

FIGURE 13 RECEIVER Heart Rate Variability Coherence by Experimental Mode

feel about each other and themselves, for that matter, was likely to have been affecting the HRVC coherence outcomes, as the feelings of familiarity and friendliness were found to be significant factors for predicting matched-case success. This makes intuitive sense as well: How people feel about each other and themselves might affect the nature and extent of any energetic interactions between them. This is also consistent with the findings of other researchers that have found that health outcomes were best in cases where patients felt that the physician was empathetic and empowering.[22-24]

Incidentally, an analysis of the psycho-physiological changes of sustained coherence-building was conducted in support of this study to test whether various stress measures such as cortisol and DHEAS levels would change over the 2-month testing period (data to be published separately). As expected, the participants who practiced achieving high levels of HRVC over the 2-month period had significantly reduced levels of cortisol and significantly increased levels of DHEAS, both results indicating lower levels of stress. Similar results were seen in the control group, although they were not considered to be significantly different, mostly owing to the small sample of the control group. It would seem then, that all of the participants, experimental and control, benefited from having the 16 educators learn and practice achieving high coherence. These results suggest that a form of "social coherence" is forged over time through the sharing of common experiences, with everyone in the school community potentially reaping some of the benefits of the group's coherence as it develops from the beginning of term to the end of term, with the largest benefits accruing to those who routinely practiced achieving high HRVC.

This is exactly what happens in the case of well-performing teams: as social, or group, coherence is forged through the sharing of common experiences, intergroup awareness and communications increase. Of course, all of the inter-group relationships are two-way channels themselves so each must be coherent itself in order to establish and sustain group coherence. Lastly, and perhaps most importantly, it was seen that the quality of these relationships directly impacts a group's collective coherence as well as its performance.

CONCLUSION

This study set out to establish whether a group of participants trained in achieving high states of HRVC could facilitate higher levels of HRVC in an untrained subject. This was verified by a test of differences in mean values of HRVC measures. Specifically, a significant positive difference was found between mean HRVC for receivers in SND:RLX mode compared to those in ACH:RLX mode. In addition, a significant positive difference was found between mean HRVC for receivers in SND:RLX mode compared to those in RLX:RLX mode. Significant differences in mean HRVC measures also were found in about half of all trials involving same participants (matched comparison analysis).

A test of differences in means showed that receiver HRVC scores were higher, on average, when senders were attempting to facilitate the receiver's HRVC (SEND mode) as opposed to when they were merely relaxing (RELAX mode) or when they were focusing on achieving their own high levels of HRVC (ACHIEVE mode). However, these differences were only significant in cases where the receiver was relaxing (RELAX mode) and not when they themselves were also attempting to achieve high HRVC (ACHIEVE mode). In these instances, no significant differences in mean receiver HRV and HRVC measures were observed between the various sender modes. A probit analysis revealed a statistical relationship between case success and how participants felt about each other, as well as how senders felt about themselves. The quality and extent of interpersonal relationships was found to improve the likelihood of senders positively influencing receiver HRVC.

The use of several analytical techniques revealed multiple layers of phase synchronization and lag synchronization in the heart rate time series between group members. The inherent correlations between heart rhythms was so strong that, in many instances, one person's heart rate time series could be predicted with lagged values of another's, as was made evident by the prevalence of Granger causality relationships found between the heart rhythms of subject pairs. Further evidence of synchronization was seen through the squared wavelet coherence analysis of paired heart rate time series data, which revealed the strength of correlation in the time-frequency domain. Much evidence of heart-to-heart synchronization across participants was found, further opening up the possibility for heart-to-heart bio-communications.

Collectively, these findings suggest that people in small social groups have a subtle yet persistent influence on each other's heart rhythms, and through that interaction, they can and will influence each others' HRVC. That being the case, it would be in our mutual best interest to practice emotional empathy, as the energetic interactions between people are likely to be influenced by the qualitative aspects of our thoughts and emotions. Furthermore, it is best that we not try to impose these states on others, as over-engaging the mind relative to the heart seems to impede rather than to enhance energetic interactions, giving further credence to the old adage, "take care of yourself before taking care of others." Put another way, collective coherence can best be forged on the strength of personal coherence.

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