RESEARCH ARTICLE

Original Findings Confirmed in Replication Study: Provocation with 2.4 GHz Cordless Phone affects the Autonomic Nervous System (ANS) as measured by Heart Rate Variability (HRV)

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Abstract

This is a double-blind, placebo-controlled replication of a study that we previously conducted in Colorado with 25 subjects designed to test the effect of radio frequency radiation (RFR) generated by the base station of a cordless phone on heart rate variability (HRV). In this study, we analyzed the response of 69 subjects between the ages of 26 and 80 in both Canada and the USA. Subjects were exposed to radiation for 3-min intervals generated by a 2.4-GHz cordless phone base station (3–8 microW/cm^2). Prior to provocation we conducted an orthostatic test to assess the state of adrenal exhaustion, which interferes with a person's ability to mount a response to a stressor. A few participants had a severe reaction to the RFR with an increase in heart rate and altered HRV indicative of an alarm response to stress. Based on the HRV analyses of the 69 subjects, 7% were classified as being "moderately to very sensitive", 29% were "little to moderately sensitive", 30% were "not to a little sensitive" and 6% were "unknown". These results are not psychosomatic and are not due to electromagnetic interference. Twenty-five percent of the subjects' self-proclaimed sensitivity corresponded to that based on the HRV analysis, while 32% overestimated their sensitivity and 42% did not know whether or not they were electrically sensitive. Of the 39 participants who claimed to experience some electrical hypersensitivity, 36% claimed they also reacted to a cordless phone and experienced heart symptoms and, of these, 64% were classified as having some degree of electrohypersensitivity (EHS) based on their HRV response. Novel findings include documentation of a delayed response to radiation. This protocol underestimates the reaction to electromagnetic radiation and may provide a false negative for those with a delayed reaction and/or with adrenal exhaustion. Orthostatic HRV testing combined with provocation testing may provide a useful diagnostic tool for some sufferers of EHS when they are exposed to electromagnetic radiation. It can be used to confirm EHS but not to reject EHS as a diagnosis since not everyone with EHS has an ANS reaction to electromagnetic radiation.

Keywords: heart rate variability, mobile phone, tachycardia, arrhythmia, microwave radiation, radio frequency radiation, electrohypersensitivity, autonomic nervous system

1. Introduction

Individuals who complain of electrical hypersensitivity experience a myriad of symptoms that may include heart palpitation, arrhythmia, tachycardia, pain or pressure in the chest that may or may not be accompanied by anxiety, dizziness, nausea and headaches[1,2,3,4,5]. Monitoring the effect of electromagnetic radiation (EMR) on the heart is relatively straightforward since we have the tools to measure the activity of the heart and the autonomic nervous system (ANS).

In 2010, we published a proof-of-concept study[6] that asked a basic questions, “Does the electromagnetic radiation (2.4 GHz) from a cordless phone affect the heart?” A cordless phone base station was selected for this provocation because it emits pulsed microwave radiation when the base station is plugged into an electrical outlet, and – unlike a cell phone – subjects are not required to talk and hence there is less human activity that may interfere with heart rate (HR) and heart rate variability (HRV). Andrzejak[7] tested the effect of mobile phones on HRV in healthy volunteers and they observed a change in the autonomic balance with an increase in the parasympathetic nervous system (PNS) and a decrease in the sympathetic nervous system (SNS), but they could not rule out the effect of talking on the phone.

In our proof-of-concept study, 10 out of 25 subjects (40%) in Colorado responded to the EMR generated by the cordless phone. In these subjects, response and recovery were immediate. The common responses documented were an increase in HR (tachycardia), upregulation of the SNS and downregulation of the PNS similar to a *fight-or-flight* stress response. The severe and moderate responders had a much higher low frequency/high frequency (LF/HF) ratio (SNS/PNS) than those who either did not respond or had a mild reaction to the radiation exposure from the cordless phone.

We repeated this study with an additional 75 subjects from Canada and the USA and provide the HRV results here. The analysis of the wellness questionnaire is provided elsewhere[8].

2. Primer on Heart Rate Variability (HRV) and the Autonomic Nervous System (ANS) based on Nerve Express

The Nerve Express technology, developed by Alexander Riftine, provides a quantitative assessment of the ANS based on HRV. The theoretical basis and clinical use are available[9] and only a brief description will be provided here to make the content easier to understand, since some graphics are specific to Nerve Express. Nerve Express has both CE and EU approval and is a class two medical device in Canada and in the European Union.

2.1 Orthostatic testing

2.1.1 Rhythmograph

Orthostatic testing is done to determine the response of the ANS to mild stress experienced when a person moves from a supine (lying down) to an upright (standing) position. This test is based on the time intervals between the R–R beats of the heart over a period of 448 beats (frequency interval) and is demonstrated as a rhythmograph. Figure 1 provides examples for four different conditions.

A healthy and physically fit person (Figure 1a) has high HRV – as shown by the regular undulations; a sharp decrease (elevated HR) and rapid recovery in the R–R interval during the transition phase (beats 192–256). The HR is generally low and increases marginally with exertion.

An unhealthy person with poor physical fitness (Figure 1b) has a flat rhythmograph (low variability); a shallow dip during transition to standing; and an elevated HR with and without exertion.

Atrial fibrillation (Figure 1c), the most common cardiac arrhythmia, is shown by the multiple spikes or extra systoles, which are extra contractions of the heart that interrupt the normal regular rhythm of the heart. They occur when there is electrical discharge from somewhere in the heart other than the sino-atrial node.

Episodic tachycardia (Figure 1d) is represented by the sudden decrease in the R–R Interval, which indicates a faster HR. In this case, the HR increased from 59 to more than 120 beats per minute while the person was lying down and remained elevated for the duration of the test period.

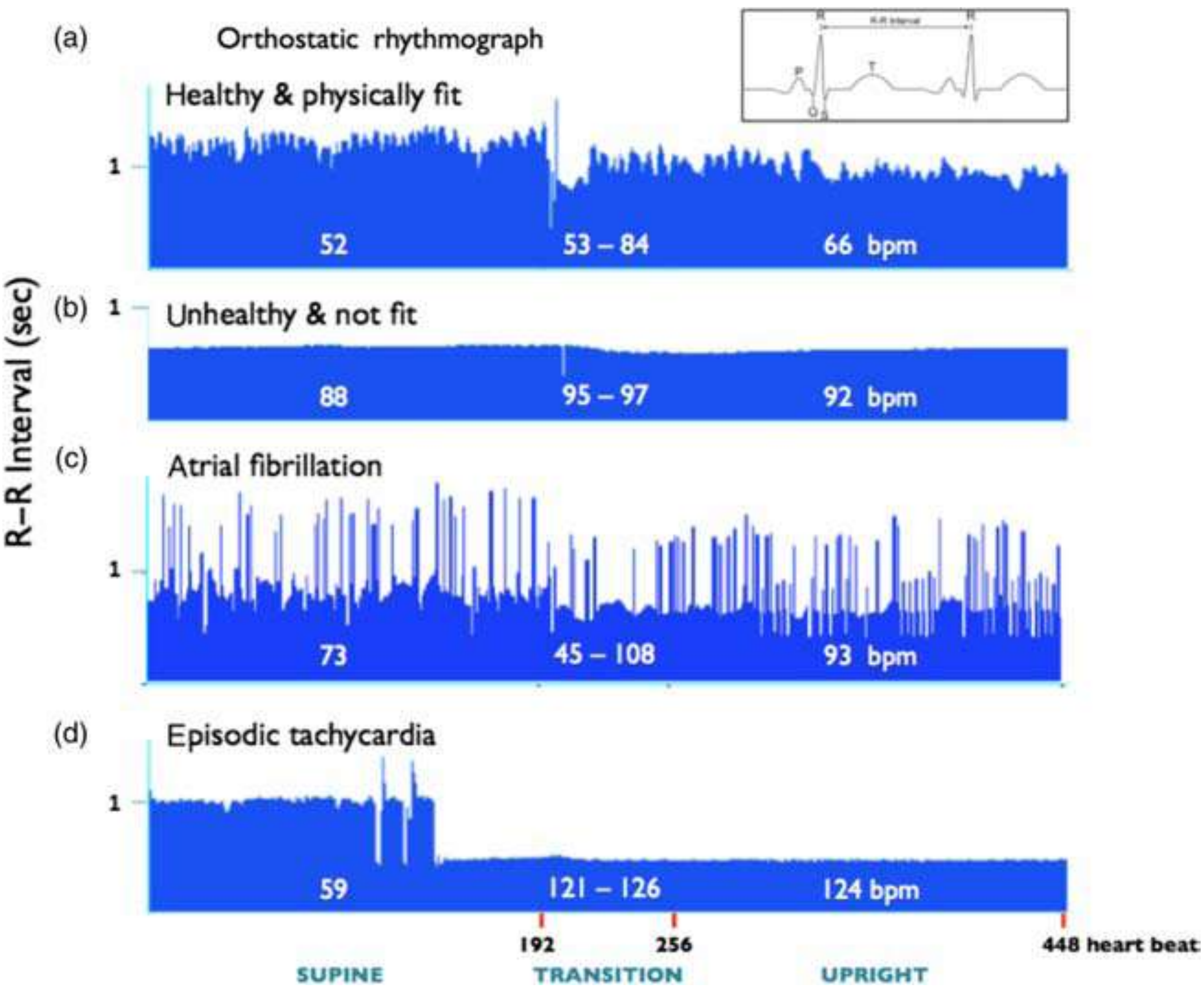

Figure 1. Examples of the Nerve Express orthostatic rhythmograph for different conditions.

2.1.2 Sympathetic Nervous System (SNS) versus Parasympathetic Nervous System (PNS)

Changes in the SNS (fight-or-flight) and the PNS (rest-and-digest) as one moves from a supine to an upright position are shown in Figure 2. How the body regulates the SNS/PNS can provide valuable information on the relative health of the ANS and based on the direction and magnitude of the response can indicate chronic or temporary dysfunction, pathology and degeneration.

Just as a stressor or physical activity can increase the ratio of SNS to PNS, eating a large meal immediately before HRV testing can also alter this ratio, but in the opposite direction making a person feel tired or sleepy. This postprandial somnolence (sleepiness following a meal) has two components:

(1) Parasympathetic upregulation, in response to food in the stomach and small intestine, combined with sympathetic downregulation shifting the body into a "rest-and-digest" state.

(2) Hormonal and neurochemical changes associated with glucose metabolism and insulin secretion. For this reason, it is important to standardize when, how much and the type of food consumed prior to testing or, if this is not possible, to record time since last meal was consumed.

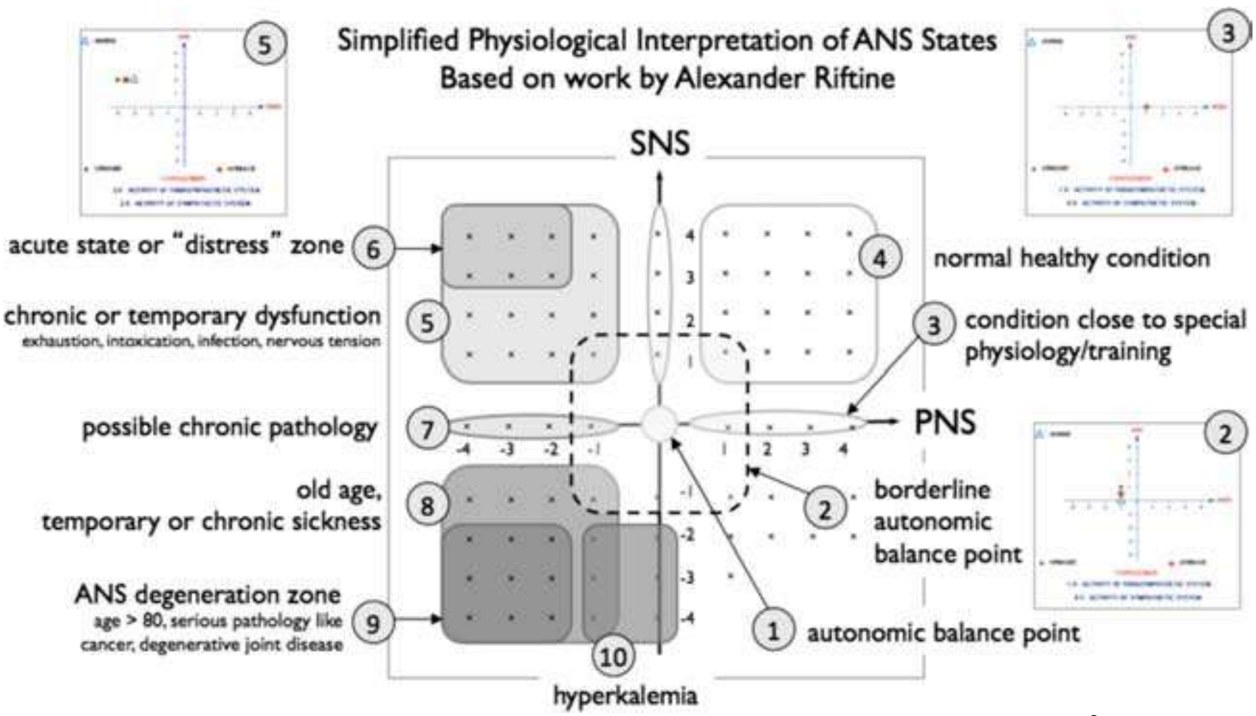

Figure 2. Interpretation of the ANS response for the orthostatic test based on Riftine[9].

2.1.3 Fitness and adaptability

The physical fitness score (Figure 3) is a combination of the short-term state of the physiological system (1–13, horizontal axis), which can change quickly and reflects how well rested the person is; and the long-term adaptability of the system (1–7, vertical axis), which changes more slowly. Top athletes rank in the blue zone (top left corner) and those who are chronically ill in the red zone (bottom right). Healthy individuals fall within the green zone (middle area) and their relative fitness is a function of how close they are to the two extremes.

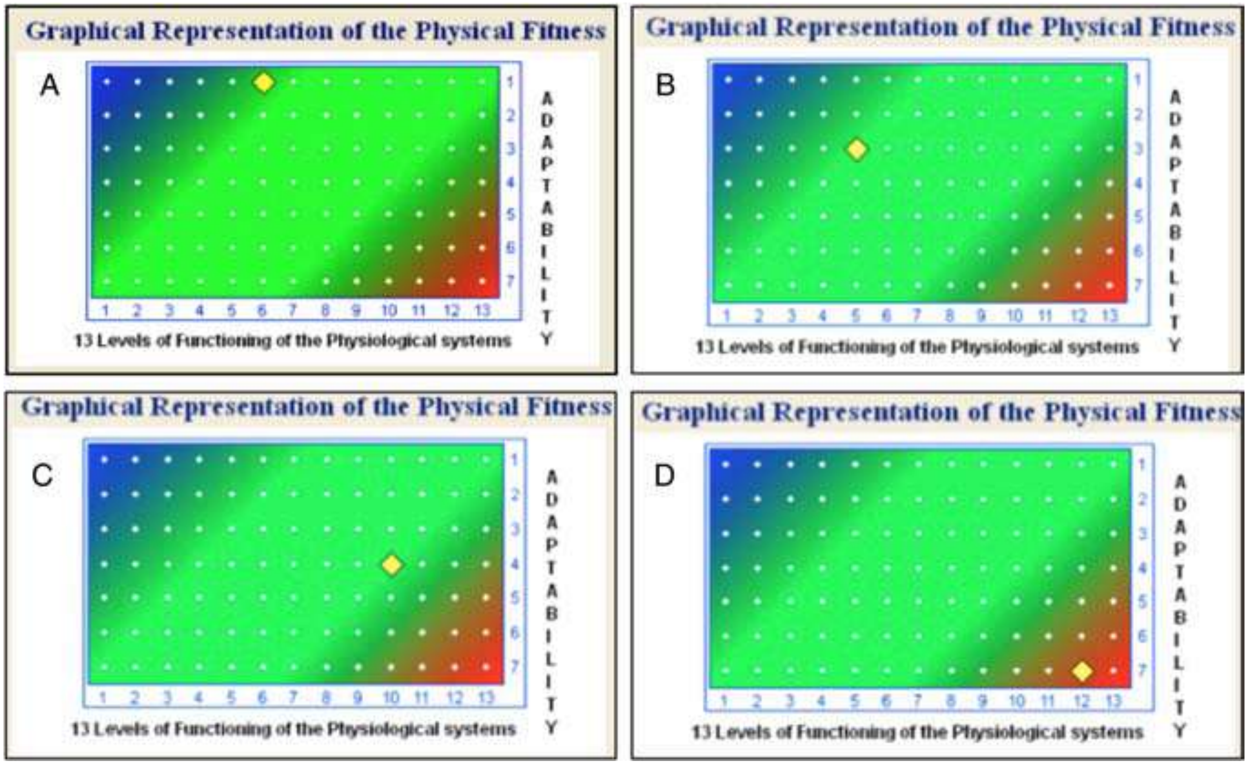

Figure 3. Physical fitness based on the orthostatic test. Top athletes fall within the upper left corner (blue) and those with chronic illness in the bottom right corner (red). Fitness decreases as one approaches the lower right corner of the graph. A fitness score at and above 10 (horizontal axis) indicates fatigue. The relative fitness of the four examples decreases from A (6–1) to D (12–7).

2.2 Real-time monitoring

During real-time monitoring, stages can be set for data analysis which are based on a pre-determined number of heart beats (frequency interval). In this study, we set the stage length (or refresh rate) to 192 R–R intervals (approximately 3 min duration depending on heart rate). Data provided include HR, HF, LF1, LF2, SNS and PNS in a table. The latter two are also provided graphically and the R–R interval is presented as a rhythmograph (Figure 4).

Definition of terms and acronyms:

- HR – heart rate (beats per minute).
- HF – high-frequency variations (0.15 and 0.5 Hz) are highly correlated with the activity of the PNS.
- LF – low-frequency variations (0.04 to 0.15 Hz) are used to assess activity of the SNS although these are not as precise as for HF; the LF bandwidth is further divided into LF1 (reflecting adrenergic and cholinergic response) and LF2 (reflecting changes in baroreceptors, also known as the Mayer waves below 0.1 Hz or 10-s waves).
- SNS – sympathetic portion of the ANS regulates the "fight-or-flight" response resulting in an increase in HR in preparation for activity.
- PNS – parasympathetic portion of the ANS regulates the "rest-and-digest" response and counterbalances the SNS by bringing the heart back to a resting state once the "stressor" is no longer present or the activity is reduced.

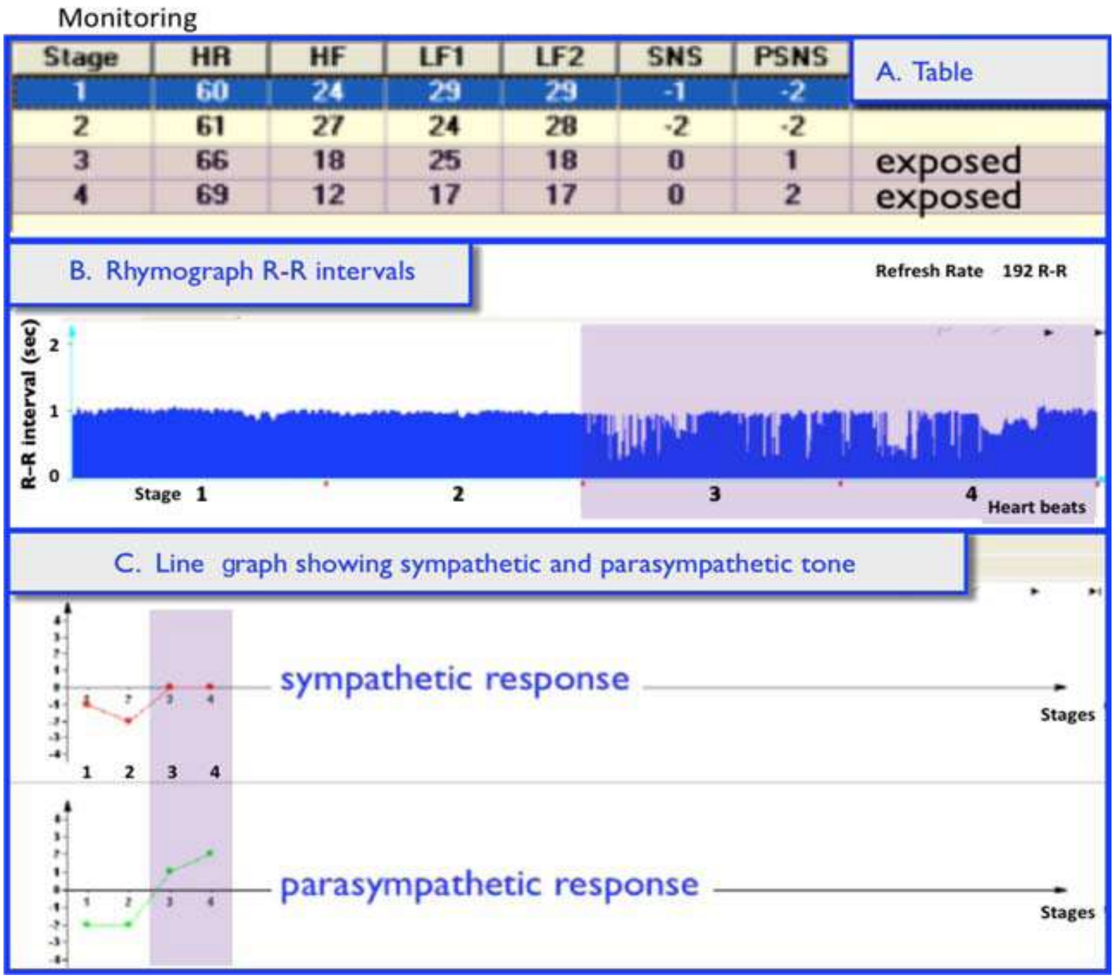

Figure 4. Real-time monitoring of exposure showing HR, HF, low frequency (LF1 and LF2), SNS, PNS and the time interval for the heart beats (R–R interval). The example provided shows exposure during stages 3 and 4.

3. Material and Methods

This was a double-blind, sham-controlled study. The same recruiting method and the same testing protocol for measuring the electromagnetic environment and for monitoring heart rate variability (HRV) were followed as in the previous study[6]. Only situations specific to this study and related to the functioning of the ANS are provided here.

3.1 Volunteers

In this study, 75 subjects volunteered to be tested in six locations during the period October 23, 2008 to March 1, 2009. Subjects were recruited by word of mouth based on their availability during a short period of testing and excluded anyone who was pregnant, under the age of 18, and/or with a serious heart conditions. Testing was done in either a private home or doctor's office in five U.S. cities (San Francisco, CA; Tucson, AZ; Santa Fe, NM; Taylor, WI and New York, NY) and one Canadian city (Simcoe, ON). All subjects completed a wellness questionnaire that is published elsewhere[8].

3.2 Background Levels of Electromagnetic Fields/Radiation

For studies such as this it is essential that the background levels of electromagnetic fields and electromagnetic radiation are as low as possible.

We measured the extremely low frequency magnetic field (ELF MF), power quality (PQ), and radio frequency/microwave (RF/MW) radiation.

ELF MG was measured with an omni-directional trifield meter calibrated at 60 Hz with a frequency-weighted response from 30 to 500 Hz and a flat response from 500 to 1000 Hz with an accuracy of $\pm$ 20%.

Power quality was measured with a microsurge meter that measures high frequency transients and harmonics between 4 and 150 kHz (intermediate frequency range). This meter provides a digital reading from 1 to 1999 of dv/dt (change in voltage/change in time) expressed as GS units with a +/- 5% accuracy. GS filters were installed where levels exceeded 50 GS units to improve power quality. The results recorded are with GS filters installed.

All wireless devices (cell phones, cordless phones, wireless routers) were turned off or unplugged prior to and during the testing. Radio frequency radiation from outside the testing area was measured with an electrosmog meter, which has an accuracy of ±2.4 dB within the frequency range of 50 MHz to 3.5 GHz. Measurements were conducted using the omni-directional mode and were repeated during the testing.

The electrosmog meter was also used to determine the exposure of test subjects during provocation with a digital cordless phone base station. This cordless phone base station emits RFR when the base station is plugged into an electric outlet. This happens even when the phone is not in use. We used the base station of an AT&T 2.4 GHz phone (digitally pulsed at 100 Hz) to expose subjects to MW radiation.

3.3 HRV Testing

Two types of HRV testing were conducted. The first was an *orthostatic* test and the second was *continuous monitoring* of heart rate variability with and without provocation (i.e. exposure to MW frequencies from a digital cordless phone base station). Nerve Express software was used for HRV testing.

An electrode belt with transmitter was placed on the person’s chest near the heart, against the skin. A wired HRV cable with receiver was clipped to the clothing near the transmitter and connected to the COM port of the computer for acoustical-wired transmission (not wireless). This provided continuous monitoring of the interval between heartbeats (R-R interval).

For the *orthostatic* testing subject laid down on his/her back and remained in this position for 192 R-R intervals or heartbeats (approximately 3 minutes), at which time a beep from the computer indicated that the person stand up and remain standing until the end of the testing period, which was 448 intervals (approximately 7 minutes depending on heart rate).

For the *provocation* testing, subject remained in a lying down position for the duration of the testing. A digital cordless phone base station, placed approximately 30 to 50 cm from subject’s head, was then connected randomly to either a live (real exposure) or dead (sham exposure) extension cord. It was not possible for the subject to know if the cordless phone was on or off at any one time. Continuous real-time monitoring recorded the interval between each heartbeat. Data were analyzed by timed stages consisting of 192 R-R intervals (heartbeats).

The sham exposures are referred to as either pre-MW exposure or post-MW exposure to differentiate the order of testing. Since type of exposure was done randomly in some instances either the pre-MW or the post-MW is missing. Subjects who reacted immediately to the cordless phone were retested with more real/sham exposures. When subject was exposed multiple times, only the first exposure was used for comparison. Provocation testing took between 9 to 30 minutes per subject.

The results of the orthostatic testing and provocation testing were sent to one of the authors (JM) for interpretation. No information was provided about the subject's self-proclaimed EHS and the information about exposure was blinded. JM did not examine the provocation results until he reviewed the orthostatic results.

4. Results and Discussion

4.1 Test Subjects

Participants ranged in age from 26 to 80 with 82% between the ages of 40 and 70; most were female (73%). Additional information is provided elsewhere[8]. The data for six participants were not included in the final HRV analysis: one had atrial fibrillation that prevented accurate analysis (Figure 1c); another experience episodic tachycardia that was not related to exposure (Figure 1d); and either missing data or compromised testing protocol eliminated the remaining four. The HRV analysis is based on a total of 69 participants.

4.2 Electromagnetic Exposure in Test Environment

Environments were selected for low background levels of anthropogenic electromagnetic exposure (Table 1). Extremely low frequency magnetic fields (ELF MF) ranged from 0.2 mG (Taylor, WI) to 1.5 mG (New York, NY). Power quality was between 30 GS units (San Francisco, CA) and 109 GS units (New York, NY). Radio frequency radiation was undetected (less than 0.004 microW/cm^2) in all but two environments where levels were low (0.01–0.05 microW/cm^2 in Tucson and New York, respectively).

Table 1. Measurement of the electromagnetic environment at each testing location.

Location	Date of testing	No. of subjects tested	Background levels		
			Magnetic field (mG)	Dirty electricity (GS units)	Radio frequency (μW/cm^2)
San Francisco, CA	23–24 Oct 2008	21	0.5	30	<0.004
Simcoe, ON	15 Nov 2008	7	0.4	60	<0.004
Taylor, WI	24 Nov 2008	10	0.2	48	<0.004
Tucson, AZ	20 Dec 2008	9	0.8	60	0.05
Santa Fe, NM	21 Dec 2008	11	0.6	42	<0.004
New York, NY	26 Feb–1 Mar 2009	17	1.5	90–110	0.01

The radiation generated by the cordless phone was between 3 and 8 microW/cm^2 at the closest body part (head) of each test subject while subject was lying down during the provocation portion of this study. Exposures (real and sham) were for periods of approximately 3 min and were randomized. Neither the subject nor the doctor (JM) analyzing the HRV data knew when subjects were exposed. Radiation from the cordless phone base station was ~100–1000 times higher than background levels in the test environments and was considerably lower than the guidelines recommended by International Commission for Non-Ionizing Radiation Protection (ICNIRP) for 2.4-GHz radiation of 1000 microW/cm^2. Maximum exposure to radiation from the cordless phone was at 0.8% of ICNIRP guidelines. The guidelines are similar in Canada and the USA, although in Canada public exposure is averaged over a 6-min period and in the USA over a 30-min period. Neither country has long-term exposure guidelines. Note also that these guidelines are based on a thermal effect of increasing body temperature. They do not consider more subtle effects such as changes in cardiac function.

4.2.1 Assessment of Electrohypersensitivity Status

Determining whether or not a subject is "responding" to provocation is fairly straight forward in those subjects who mount a significant response during or immediately after exposure to the radiation through changes in the rhythmograph, heart rate and/or the relative ratio of sympathetic to parasympathetic tone. In "non-responders" there is no significant change in any parameter tested.

Determining whether a responder or a non-responder has electrohyper-sensitivity (EHS), however, is not straightforward. In this study, the intensity of the response and the number of parameters that were altered during or after exposure contributed to the EHS classification with more intense reactions labeled "very sensitive".

For example, 64% (44) of the subjects tested experienced fatigue and adrenal exhaustion based on the fitness results and the chronotropic reaction (orthostatic test). Someone with adrenal exhaustion has limited ability to mount a response to a stressor and, consequently, they could be mistaken for someone who is not electrically sensitive as they are unlikely to mount a significant response.

Examples of two non-responders are provided in Figures 5 and 6. Subject in Figure 5 was healthy and fit and did not respond immediately to the exposure and, consequently, he was classified as not sensitive. Subject in Figure 6 had dysautonomia and adrenal exhaustion and probably had limited energy to mount a response. For this reason, it was not possible to determine his EHS status. Because of this distinction, the orthostatic test is essential to assess the baseline response for each subject and to compare their monitoring results to the degree of stress experienced when standing up.

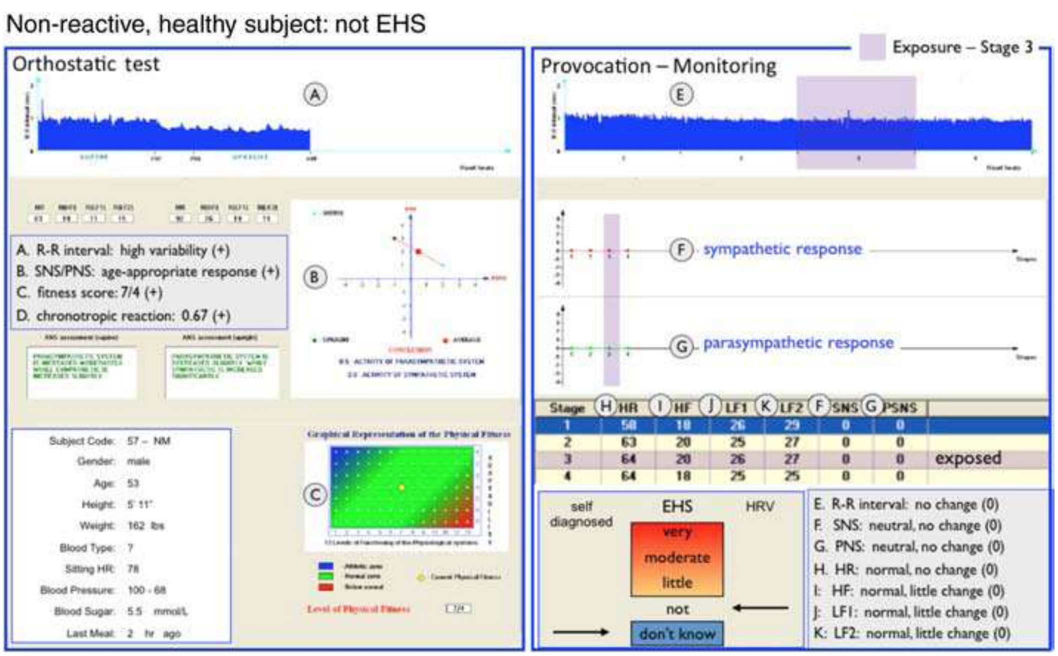

Figure 5. HRV parameters for a healthy subject who is not responding to any exposure. This subject was classified as not electrically sensitive based on short-term exposure to the radiation generated by a cordless phone base station.

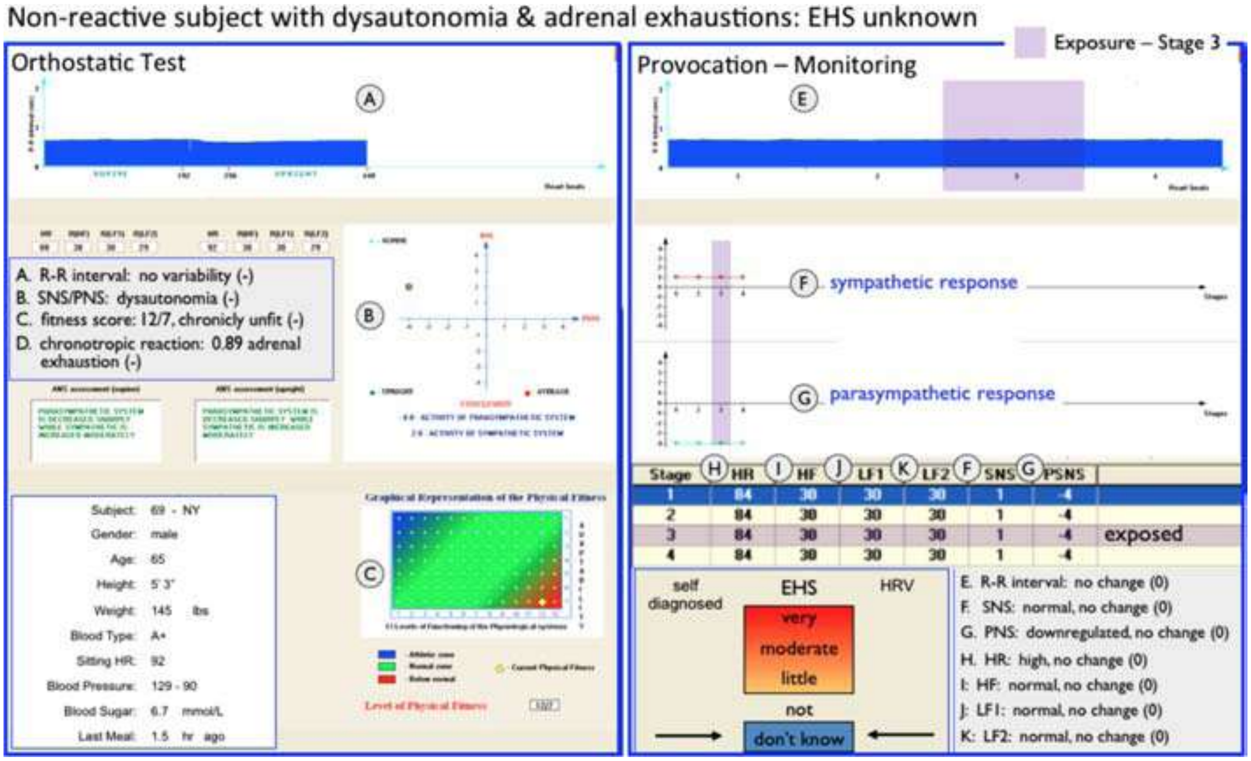

Figure 6. HRV parameters for a subject with dysautonomia and adrenal exhaustion who is not responding to any exposure. This subject's electrical hypersensitivity was classified as unknown due to adrenal exhaustion.

Examples of reactive subjects are provided in Figures 7–9. Subject in Figure 7 had sufficient energy to mount a response as can be seen in the rhythmograph (irregularity), the sympathetic and parasympathetic increase and there are changes in HF, LF1 and LF2. This subject was classified as moderately sensitive. Subject in Figure 8 had exhausted adrenals and was able to mount a significant response during the first exposure but not during subsequent exposures. He was classified as "very" sensitive. Subject with moderate fatigue (Figure 9) was able to mount a response during both sets of exposures. An upregulation of the SNS combined with a downregulation of the PNS is a typical alarm – "fight-or-flight" – reaction.

One of the test subjects mentioned that he normally responds to electromagnetic exposure with a delay of 10 min or more, so we extended the monitoring time post-exposure by approximately 30 min (Figure 10). Subject 28 began to respond post-exposure at stage 7 and the fluctuations in the rhythmograph and in SNS and PNS become increasingly common over time. Based on the strength and delayed response, this subject was classified as very sensitive. His sensitivity would have been missed had the monitoring period lasted only a few minutes. This points out one of the major weaknesses of a study that is so short, namely that a delayed response will be missed.

One way to improve the quality of data collection is to extend duration for the background condition, sham exposure, direct exposure and post-exposure and to reduce the sampling period (refresh rate) from 192 to 48 heart beats (R–R intervals).

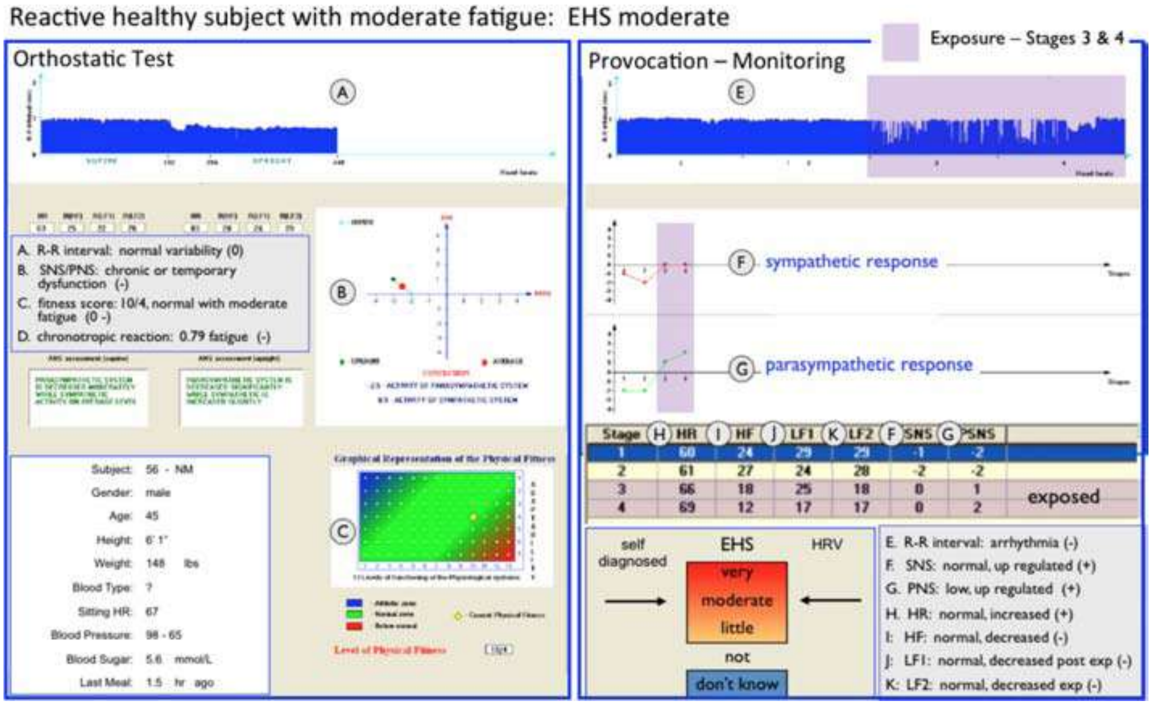

Figure 7. HRV parameters for a healthy subject with moderate fatigue who is reacting to the radiation generated by a cordless phone base station. This subject was classified as moderately sensitive.

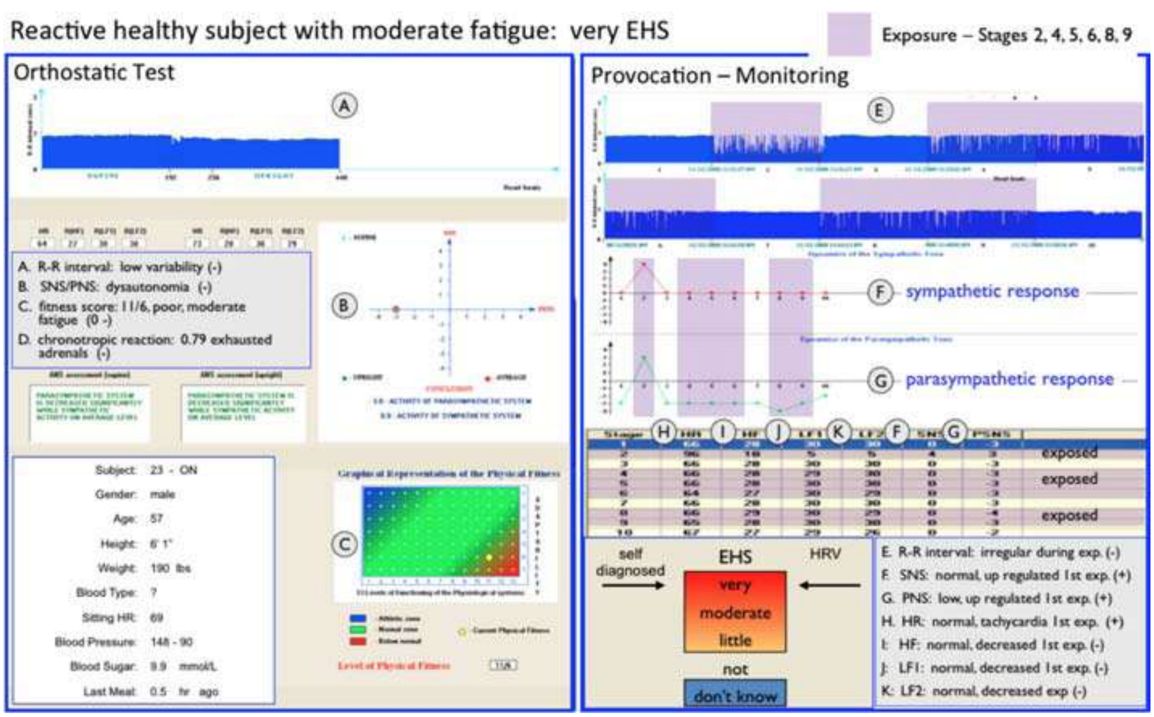

Figure 8. HRV parameters for a healthy subject with adrenal exhaustion who is reacting to the radiation generated by a cordless phone base station. This subject was classified as very sensitive due to tachycardia and sharp upregulation of both the SNS and PNS that is indicative of an alarm reaction. Subject responded primarily to first exposure perhaps due to adrenal exhaustion.

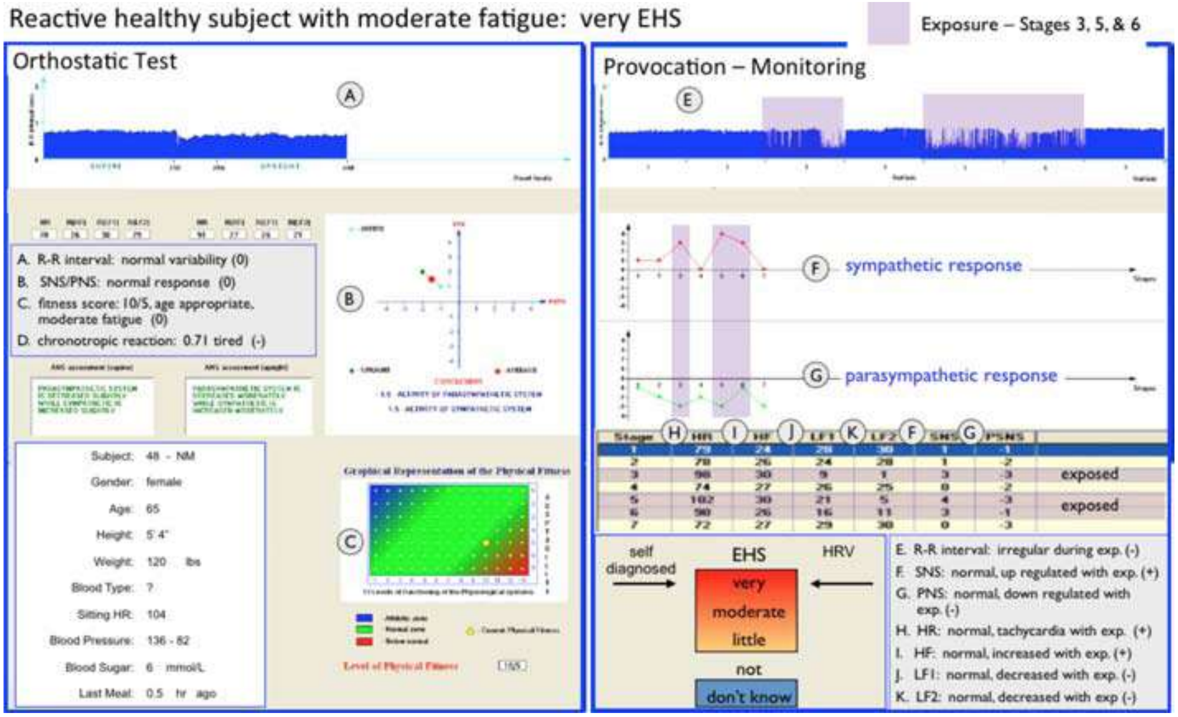

Figure 9. HRV parameters for a healthy subject with moderate fatigue who is reacting to the radiation generated by a cordless phone base station. This subject was classified as very sensitive due to tachycardia and sharp upregulation of both the SNS and PNS that are indicative of an alarm reaction. Subject reacted during all exposures.

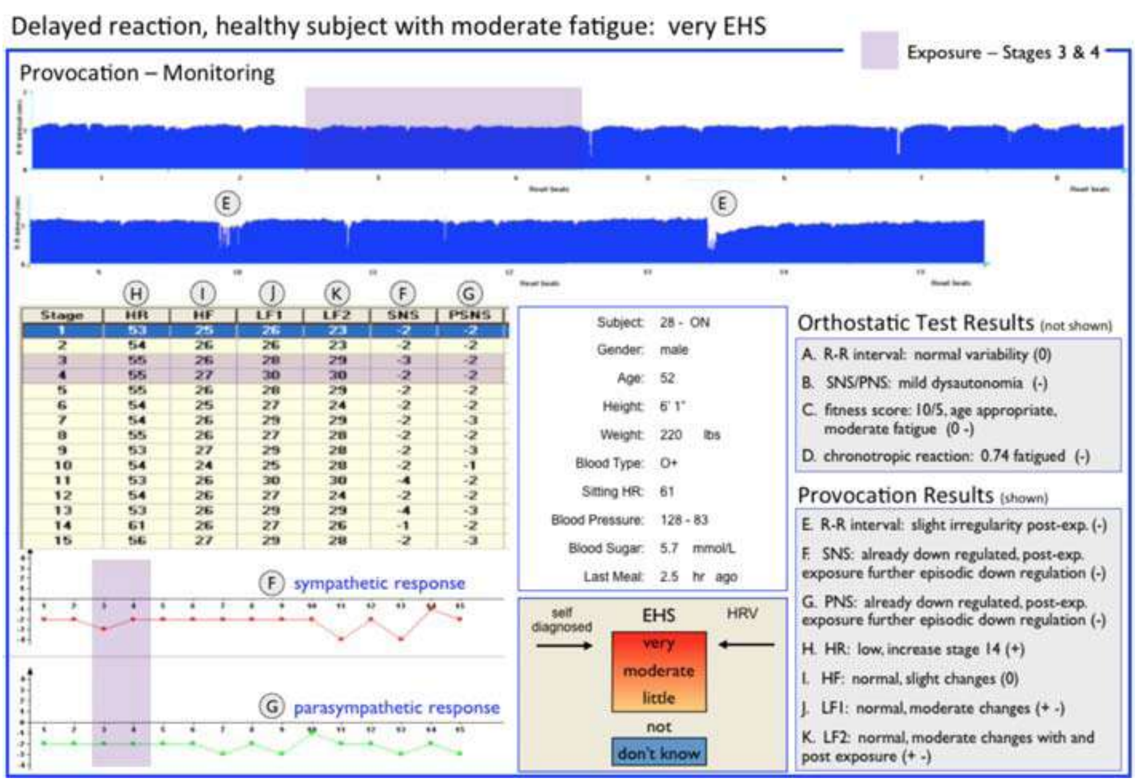

Figure 10. Healthy subject with moderate fatigue experienced a delayed reaction to radiation generated by a cordless phone base station. This subject was classified as being very sensitive.

4.2.2 Electromagnetic Interference (EMI)

Electromagnetic interference (EMI) with test equipment has been suggested in the non-peer-reviewed literature as a possible explanation for the altered HRV parameters that we documented in our first study[6]. To test this hypothesis, we repeated exposure with a blinded subject who was healthy and nonreactive and moved the radiation source from the head to the heart. This increased exposure from 2 to 100–200 microW/cm^2 at both the heart and the receiver. These levels are still below the thermal guidelines of 1000 microW/cm^2. The only change documented was a slight and temporary decrease in the PNS[8]. It is worth noting that had EMI been involved, then all of the exposures would have interfered with the technology since the identical protocol was used for all testing. Furthermore, EMI cannot explain the delayed reaction after the radiation was discontinued (Figure 10).

4.3 Provocation HRV

Of the 69 participants, 46 participants were classified (by JM) as "little to very" EHS. Of these, 18 (39%) did not know whether or not they had EHS, one (2%) believed he was not sensitive and 27 (39%) believed they were sensitive (Table 2). Indeed there was agreement with the degree of sensitivity (little to very) for 17 (25%) of the subjects. This relatively high percentage showing a convergence of assessment is not in agreement with the reviews on this subject conducted by a psychologist who states that EHS is psychosomatic rather than a physical response[10,11,12].

Table 2. Comparison of EHS status based on HRV analysis and self-proclamations. Degree of sensitivity identified as very (V), moderate (M), little (L), not (N) and don't know (?). The agreement between self-diagnosis and HRV analysis is highlighted in grey.

	EHS	EHS based on HRV Analysis						
	27 (39%)	MV	LM	NL	N	?	Total	Agreement
Self-Proclaimed EHS	V	4 (6%)	3 (4%)	7 (10%)	6 (9%)	1 (1%)	21 (30%)	4 (6%)
	M	0 (0%)	3 (4%)	2 (3%)	0 (0%)	1 (1%)	6 (9%)	3 (4%)
	L	0 (0%)	4 (6%)	4 (6%)	4 (6%)	0 (0%)	12 (17%)	8 (12%)
	N	0 (o%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)
	?	1 (1%)	9 (13%)	8 (12%)	9 (13%)	2 (3%)	29 (42%)	2 (3%)
	Total	5 (7%)	20 (29%)	21 (30%)	19 (28%)	4 (6%)	69 (100%)	17 (25%)
	Agreement	4 (6%)	7 (10%)	4 (6%)	0 (0%)	2 (3%)	17 (25%)	

Of the 69 participants, 57% (39) were self-proclaimed electrosensitives; 42% (29) stated they reacted to a cordless phone (sometimes to always) and 32% (22) experienced some heart-related symptoms that could be detected by the HRV analysis (altered HR and/or arrythmia). Only 20% (14) of the participants claimed they experienced all three simultaneously. Of these 14 subjects, 9 (13%) were classified as being "little to very" EHS based on their HRV results.

In a questionnaire study in the Netherlands, when asked "which appliances are bothering you the most?" the Digital European Cordless Telephony (DECT) phone was at the top of the list with 38% (76) of the 189 respondents[13]. The difference between a DECT phone and the cordless phone we used in this study is the carrier frequency. DECT phones operate at 1.9 GHz and the cordless phone in this study was at 2.4 GHz. Both fall within the microwave band of the electromagnetic spectrum.

In the study mentioned above, heart rhythm problems were experienced by 17% (42) of the respondents and changed blood pressure by 10% (25) of the 250 respondents. Chronic fatigue was one of the most frequently cited health problems with 70% of the 250 respondents complaining of this symptom. Fatigue was also observed in a large percentage of subjects in the current study, and this may be a result of continuous exposure resulting in chronic stress leading to adrenal exhaustion. An alternative explanation is those who are chronically tired, for whatever reason, are more sensitive to an additional stressor on the body.

A female physician who diagnosed herself with EMF hypersensitivity was exposed under controlled conditions in a double-blind provocation study to 60 Hz, 300 V/m electric fields[14]. She experienced temporal pain, headache, muscle twitching and skipped heart beats 100 s after initiation of EMF exposure ($P \leq 0.05$), and her responses were primarily to field transitions (on-off switching) during which time high frequency voltage transients (radio frequency) are sent along electrical wires. She had no conscious perception of the field but did experience a reliable somatic reaction. The authors conclude that "EMF hypersensitivity can occur as a bona fide environmentally inducible neurological syndrome."

Why is it that some studies do not show a response to exposure? The symptoms associated with exposure are quite complex, and unlike turning on a light switch and getting light each time, the body has an internal homeostatic system that tries to maintain a healthy equilibrium. The functioning of the ANS is nonlinear and, as such, difficult to predict.

It is absolutely essential that tests conducted to determine EHS be done in an electromagnetically clean environment and that includes all forms of man-made electromagnetic pollution (extremely low frequency to radio frequency radiation). Removal of items that generate electromagnetic pollution and filtering of dirty electricity may be necessary in some environments. Travel to the test site may expose the participants to elevated electromagnetic radiation and may adversely affect the results for those who have a prolonged reaction. Both the location of testing and travel to the test site need to be considered when doing this type of provocation exposure.

Bevington[2] identifies some key parameters that need to be considered when conducting provocation studies.

- *Accumulation*: Cumulative exposures can produce symptoms, making symptoms from chronic exposure more difficult to recognize than from acute exposure.
- *Delay*: Symptoms can be delayed after acute exposure for a few hours or even days. This is said to become more common, the longer the patient has been sensitized.
- *Diurnal state*: Symptoms vary according to the diurnal state of the person's body. A person's own endogenous electromagnetic field often declines during the day.
- *Duration*: Individual symptoms can last for a short or long time. As a group symptoms can become worse. They can fade after 2–12 months without EMR exposure.
- *Frequencies*: The sufferer may react first to a single frequency or source but later to more (e.g. first to Wi-Fi but later to mobile phones and power cables).
- *Intensity*: As the condition progresses the level of sensitivity can increase; a person may first have pains from a phone next to the head but later from one at a distance of several meters.

- *Variations*: Individual variations in tissue/bone density, acidity, salt content, skin conductivity, size, etc. affect absorption. This may relate to the variety of symptoms.

Subjects have varied reactions to radio frequency exposure at levels that are well within international guidelines as recommended by ICNIRP and guidelines in both Canada and the USA. Among those who respond, the reaction may be immediate, prolonged or delayed well beyond exposure. The protocol we used in this study is likely to underestimate sensitivity or reactivity to radio frequency radiation. This protocol can be modified to consider delayed responders and needs to be modified to improve the quality of the data collection for each subject. For those wanting to repeat or conduct a similar study, we recommend the following for real-time monitoring:

- Important to wait until the ANS (PNS and SNS) has stabilized before exposure or sham exposure begins. This can be done by monitoring HR while the person is lying down. Their resting HR and SNS, PNS response should be similar to their supine orthostatic readings.
- Important to allow for longer exposure periods and longer periods of sham and post-exposure than 3 min since there can be a delayed reaction.
- Since subjects can react quickly to this type of provocation, reducing the assessment period (refresh rate) from 192 to 48 heart beats (R–R intervals) for the same or longer time period would enable a more accurate and detailed assessment.

The concept that microwave radiation may affect the heart is not new. In a 1969 Symposium Proceedings – under the auspices of the U.S. Department of Health, Education and Welfare – on the biological effects and health implications of microwave radiation[15], scientists recognized the adverse effects on the cardiovascular system and recommend that cardiovascular abnormalities be used as screening criteria to exclude people from occupations involving radio frequency exposures. That warning has not been heeded and indeed, microwave transmitters (mobile phones, Wi-Fi routers, wireless baby monitors, wireless computer games, smart meters, etc.) are now commonly used in homes, schools, work environments as well as in hospitals and doctors' clinics. If our results are real and if exposure continues to increase, we are likely to observe an increase in heart-related problems among younger people and among those whose immune system is compromised.

5. Conclusion

Our results show that a 36% of the individuals tested reacted via altered heart rate variability (HRV) to the non-ionizing radiation generated by a cordless phone base station in this double-blind, placebo-controlled study. These reactions were not psychosomatic. In this study, we document an increased heart rate (HR), altered HRV and changes in the sympathetic and parasympathetic control of the autonomic nervous system (ANS) typical of a *fight-or flight* stress response. These results are similar to our previous study. The results are not due to electromagnetic interference (EMI), since we have examples of a delayed response after the radiation was turned off and have tested EMI with much higher exposure using the same technology with no reactions noted. Our results demonstrate that the radiation from a 2.4-GHz cordless phone affects the ANS and may put some individuals with preexisting heart conditions at risk when exposed to electromagnetic frequencies to which they are sensitive. Individuals fell into 3 categories: those who had a healthy ANS and were able to tolerate the stress without reactions; those who reacted; and those who had a compromised ANS with adrenal exhaustion and were unable to mount a response leading, in some cases, to a false negative result. Although documenting a response is relatively simple, determining the degree of EHS is quite complex and requires further study especially for those with a compromised ANS.

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Declaration of interest

MH has no conflict of interest. Bioenergimed Metabolic Institute sells medical products including the Nerve Express.

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