Diplomarbeit

EFFECTS OF COMPLEX STRESSORS ON HEART RATE VARIABILITY IN AN ANTARCTIC SPACE ANALOGUE ENVIRONMENT

eingereicht von

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zur Erlangung des akademischen Grades

Doktor der gesamten Heilkunde

(Dr. med. univ.)

an der

Medizinischen Universität Graz

ausgeführt am

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Graz, 6.12.2016

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ACKNOWLEDGEMENTS

I would like to give thanks to my supervisors Ass.-Prof. Priv.-Doz. Dr.med. Nandu Goswami, PhD. and Univ. Prof. Dr. phil. Maximilian Moser. Their patient and constructive feedback have made it possible to write this diploma thesis, and I have learned many important lessons from them for my future endeavors in the medical profession.

I also owe thanks to the Medical University of Graz for making the resources needed for this study available and for enabling my career as a medical doctor.

I especially want to thank my family and friends for their continuous support. Their encouragement and faith in me have led me to this point, without them I would never have achieved my goals.

Special thanks go to my partner Beate for being a constant source of motivation, love and support, and to my father, who always had useful advice and a listening ear when I got stuck.

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ABBREVIATIONS

GCR	Galactic Cosmic Radiation
SPE	Solar Particle Event
ISS	International Space Station
NASA	National Aeronautics and Space Administration
ESA	European Space Agency
ICE	Isolation, Confinement, Extreme Environment
ANS	Autonomic Nervous System
SNS	Sympathetic Nervous System
AV	Atriventricular
PSNS	Parasympathetic Nervous System
HR	Heart Rate
HRV	Heart Rate Variability
HF	High Frequency
RSA	Respiratory Sinus Arrhythmia
LF	Low Frequency
VLF	Very Low Frequency
ULF	Ultra Low Frequency
ECG	Electrocardiogram
SDNN	Standard deviation of normal-normal intervals
SDANN	Standard deviation of the averages of normal-normal intervals in all 5-minute segments of the entire recording
RMSSD	The square root of the mean of the sum of the squares of differences between adjacent normal-normal intervals
SDNN index	Mean of SDNN for all 5-minute segments of the entire recording
SDSD	standard deviation of differences between adjacent NN-intervals
NN50	Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording
pNN50	NN50 count divided by the total number of all NN intervals
TINN	Baseline width of the minimum square difference triangular interpolation of the highest peak of the histogram of all NN intervals
HRI	Human Research Institute
CCG	Chronocardiogram
ES	Extrasystole
AR	Artifact
MSP	Main Sleep Phase
ASP	Additional Sleep Phase
M	Measurement Week
logRSA	common logarithm of the respiratory sinus arrhythmia
ln LF	natural logarithm of the LF band
ln HF	natural logarithm of the HF band
ln TOT	natural logarithm of the sum of the LF and HF bands
VQ	Vegetative Quotient
QPA	Pulse-Respiratory-Quotient
SQ	Sleep Quality
ms	millisecond

lg ms	common logarithm of milliseconds
ln ms²	natural logarithm of milliseconds squared
p.	Percentile

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ABSTRACT

Introduction: Long-term spaceflight features prolonged confinement and isolation, which could influence team interaction and cohesion. Routinely, isolated and confined environments (ICE) are used to study the effects of long-term isolation and confinement on group dynamics. However, the effects of long-term isolation on physiological parameters such as hemodynamics and autonomic function remain largely unstudied.

Aim: This DA investigated heart rate and autonomic function changes in a winter-over team staying at an ICE environment. It also aimed at establish a link between the time spent in isolation and its effects on autonomic function. It was hypothesised that there is a correlation between autonomic changes and the exposure time to the ICE environment.

Methods: The isolation study was carried out at Concordia station, a European station located in the Antarctic. Due to its remoteness, it is routinely used by the European Space Agency (ESA) to assess isolation effects on psycho-physiological parameters. Ten members of the winter-over team staying in Concordia for over nine months were investigated. Heart rate and heart rate variability (HRV) were used as an index of autonomic function. For each individual SPSS was used to compare the HRV recordings over time. As the individual members´ results were only compared to those of the same member over time, the results were unique for each participant and not representative of any group of subjects. Therefore, the results were presented as case studies.

Results: The results showed that the HRV parameters behaved very differently in each subject. While some had very high values, others had HRV values far below average, and the values often fluctuated from one day to the next more than they did from one month to the next. In the frequency spectrum analysis some members of the expedition showed periodic breathing, while others had respiratory sinus arrhythmia.

Discussion: The findings suggest that autonomic adaptation to ICE environments is not primarily dependant on the time spent there, but rather on the individual´s resiliency to chronic stress. Further research is necessary to find out how to utilise and maximise this resiliency.

ZUSAMMENFASSUNG

Einführung: Die Raumfahrt beinhaltet langzeitige Isolation und den Aufenthalt in einem sehr begrenzten Raum. Beides kann die Interaktionen und die Zusammenarbeit im Team beeinflussen. Daher werden solche Umgebungen (ICE) routinemäßig für Forschungszwecke verwendet. Die Auswirkungen langzeitiger Isolation auf die Hämodynamik sowie das autonome Nervensystem blieben bislang fast unerforscht.

Ziele: Diese Diplomarbeit befasste sich mit den Änderungen in der Herzrate und der autonomen Funktionen in einer ICE-Umgebung. Sie versuchte eine Verbindung zwischen der verbrachten Zeit und ebendiesen Funktionen herzustellen.Die Hypothese lautete, dass ein Zusammenhang zwischen der Zeit in der Umgebung und den Änderungen der autonomen Funktionen besteht.

Methoden: Die Isolationsstudie wurde in der europäischen Station Concordia in der Antarktis durchgeführt. Aufgrund ihrer Abgeschiedenheit wird sie regelmäßig von der Europäischen Raumfahrtsbehörde (ESA) zur Untersuchung psycho-psysiologischer Veränderungen in extremer Isolation genutzt. Zehn Mitglieder eines Forscherteams wurden neun Monate lang untersucht. Die Herrate und Herzratenvariabilität wurden als Indices für das autonome Nervensystem benutzt. Bei jedem Individuum wurden mithilfe von SPSS die HRV-Messungen chronologisch verglichen. Da die Messungen nur mit denen derselben Person vergleichen wurden, sind die Ergebnisse einzigartig und nicht repräsentativ. Daher handelt es sich um Fallstudien.

Resultate: Die Werte hatten individuell unterschiedliche zeitliche Verläufe. Während bei manchen Untersuchten die HRV-Parameter schon beim ersten Messtermin sehr niedrig waren und sich kaum erhöhten, waren bei anderen die Werte während des gesamten Aufenthaltes sehr hoch. Andere wiederum hatten entweder steigende oder absinkende Werte.

Diskussion: Es ließ sich kein kausaler Zusammenhang feststellen zwischen der verbrachten Zeit auf der Station und den HRV-Werten. Vielmehr scheinen die Unterschiede von der individuellen Widerstandskraft auf Stressoren abzuhängen. Weitere Forschungen sind notwendig um festzustellen, ob und wie man diese Fähigkeit verbessern kann.

1 Introduction

Mankind has long been fascinated by the vastness of space. As Plato once said: “Astronomy compels the soul to look upwards and leads us from this world to another”(1). And while our understanding of known space has expanded greatly through observations, there is also a great interest in sending people into space. To that end, space agencies were founded all around the globe with the purpose of preparing and training people to leave Earth and venture out into space. However, in order to go into space one must be aware of the changes this new environment inflicts upon our bodies and physiology. For this purpose many research programs have been funded by space agencies so as to study and understand the physiological changes in space. And this is where the topic of this thesis comes in. So to explain what this diploma thesis is about, first I am going to give an overview on the changes that occur in space.

1.1 Microgravity

The most apparent change in space is weightlessness. While we are on Earth, the planet exerts a force on us that pulls us toward its center. The gravitational pull decreases the farther we distance ourselves from its center. However, objects in Earth´s orbit are not far enough away from Earth to be immune to its gravitational pull. Instead, they move fast enough around the planet to stay above the surface but not fast enough to escape the orbit. Thus, the objects are constantly in a “state of free fall”(2), which Einstein has explained to have the same effect on the object as not being influenced by a gravitational field. This phenomenon is referred to as microgravity and it causes several issues with our physiology. Our bodies developed under the influence of gravity and thus they adapted to the constant pull. However, if that pull suddenly disappears or decreases significantly, our body immediately begins to adapt to the new environmental conditions.

1.1.1 Physiological deconditioning

One such adaptation consists of reducing the overall muscle mass. On Earth our muscles not only keep us mobile, but they constantly have to counteract gravity. In microgravitational environments, our muscles do not have to move against gravity to execute a movement, and as a result of the lesser resistance the muscles atrophy. This can be a problem in space, because due to decreased muscle mass astronauts are more prone to injuries and may be unable to perform vital tasks during extravehicular activities (3). Another issue that has to be considered is the re-entry into

environments under the influence of gravity. The affected subjects would have great difficulty moving due to their decreased muscle mass.

A similar issue to the loss of muscle mass is a decrease in bone density. Human bones are dependent on being strained. The more stress on them, the more they are reinforced by integrating calcium and the denser they get (4). In microgravity, a significant strain on our bones in the form of gravitational force disappears, leading to a decrease of bone density of 1-2 percent per month. This amount of bone loss is more than double the percentage usually seen over the course of an entire year on Earth in an average adult (5). As is the case with muscle mass loss, bone demineralization can present itself as a problem during the space mission or upon the subject´s return to gravitational conditions.

Microgravity also leads to a major shift in fluid distribution in our body. On Earth our cardiovascular system has to adapt to orthostatic changes whereby our body fluids move towards our lower extremities while standing in an upright position. In order to maintain our blood pressure our sympathetic nervous system gets activated and increases cardiac output and constricts our blood vessels. This ensures that the systemic blood pressure remains almost constant in spite of the hypovolemia in the upper body region.

In microgravity the body fluids do not move downward and instead accumulate in the torso and head. The baroreceptors in the arteries detect the increased volume and initiate countermeasures. Those consist of suppressing the renin-angiotensin-aldosterone system and releasing the atrial natriuretic peptide, a vasodilating hormone which inhibits the reabsorption of sodium in the kidneys. The vasodilation and increased diuresis lead to a decrease in plasma volume. As a result the hematocrit rises, which reduces the secretion of erythropoietin. This in turn lowers the production of red blood cells.

Due to this physiological adaptation the total blood volume is lowered by 10 percent during the first 24 hours of spaceflight (4).

The orthostatic dysregulation also leads to problems once the astronaut returns to Earth. Once gravity becomes a major influence again it pushes the fluids to the extremities once more. However the heart still has a decreased stroke volume due to the perceived hypervolemia. The combination of upper body hypovolemia and decreased cardiac output can often lead to light-headedness, heart palpitations and syncope (4).

Another consequence of microgravity is the so called “space motion sickness”. It usually occurs during the first few days in a new gravitational environment, with most astronauts improving after 2-3 days. Symptoms may include nausea, cold sweating, facial pallor and vomiting. The most

likely explanation is the fluid shift to the head, which could also cause intracranial hypertension. The combination of symptoms is probably a result of the complex interactions between the autonomic nervous system, the vestibular system, the gastrointestinal system as well as the cardiovascular system.

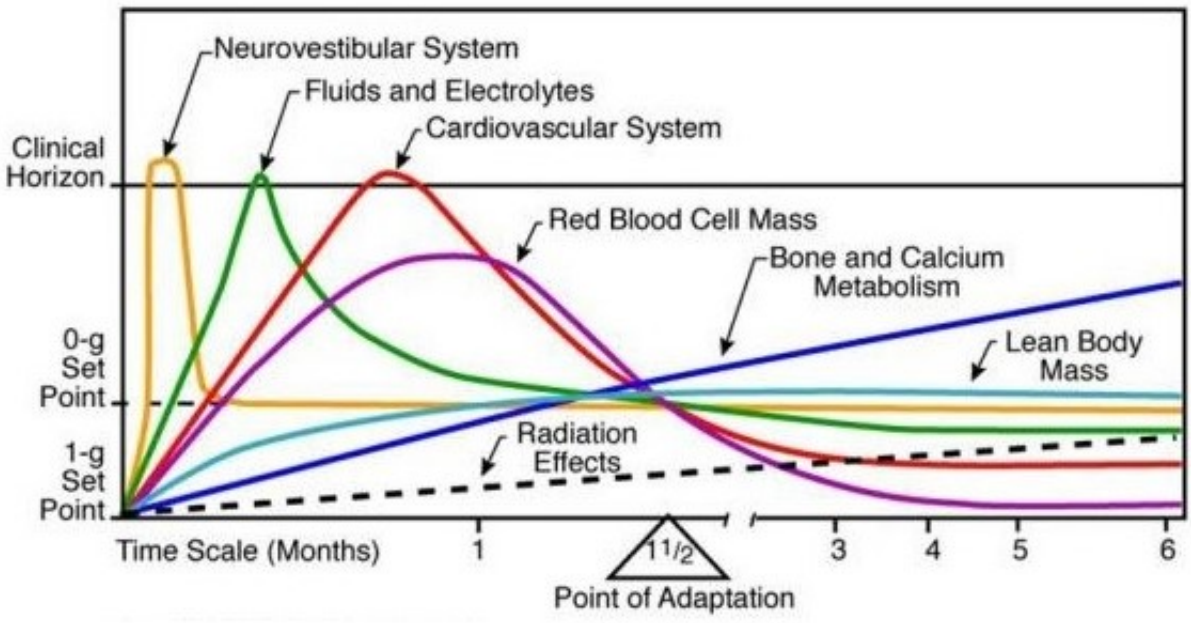


Figure 1: Time of acclimation for each different organ system (6,7); The subjects start at 1g (the equivalent of the effect of gravity at sea level) and in space each organ system has to adapt to the sudden shift into a 0g (microgravity) environment. Clinical Horizon describes the point at which the adaptation causes productivity problems (7)

Flight crews in space experience a significant dysregulation of their immune systems. Tests done on astronauts after their return to Earth have demonstrated an increased susceptibility to viral and bacterial infections. Analysis has shown that a prolonged stay in space reduces the production of white blood cells due to lymphoid organ hypoplasia and changes in blastogenesis induced by mitogens, proteins that promote mitosis in cells (4). Studies also indicate a cytokine shortage, however in contrast immunoglobulin levels appear to be mostly unaffected by space flight (4).

T-lymphocytes seem to be affected as well, as studies have shown that several genes are expressed differently in microgravity compared to cell cultures that were centrifuged during space flight (8). The 1-g-centrifuges simulate conditions in a gravitational field similar to Earth´s. Many genes that are vital for immunological pathways are down regulated. The tumor necrosis factor pathway seems to be affected early on. Consequently the hosts immune response is inadequate and promotes not only new infections but also infections of dormant viruses that were suppressed by the immune system (8).

However, the exact mechanism behind the dysregulation is still unknown. And while microgravity seems to be an important influence, other possible causes are stress, changed day-night cycles, isolation and other flight associated factors. It is still unknown if the increased exposure to radiation in space plays a role (4). To make matters worse, not only is our immune response down regulated, but bacterial cultures grown in-flight are more pathogenic than their Earth-grown counterparts (4).

Clinically the astronauts may be presented with numerous problems, including infections, auto-immune diseases, allergies, latent viral reactivations and possibly malignancies (4).

Space radiation is another important hazard for astronauts and it is one of the biggest obstacles for a manned mission to Mars.

There are several types of radiation, however only two types are considered to have enough energy levels to pose a health risk to humans: Galactic cosmic radiation (GCR) and solar particle events (SPE) (9).

GCR originates from beyond our solar system and it is still unclear how it is generated. Recently scientists have been able to determine that supernovae are a source of GCR, however they do not account for all the radiation out there, leaving room for speculation as to the other sources (10). Its main compositions are protons and alpha particles (helium core comprised of two protons and two neutrons) as well as many other elements and their isotopes, thereby mimicking the elemental composition of our own solar system (11). Accelerated almost to the speed of light they are trapped in the galactic magnetic field and travel constantly across the galaxy (11). They are highly energetic and can penetrate any shielding currently in use in our spacecraft. Also by impacting the hull secondary radiation is created which is harmful to the crew as well (12).

Our sun is also a great producer of deadly radiation. During solar flares and coronal mass ejections, it produces solar energetic particles, and for now “shielding provided by the spacecraft may not be able to completely protect astronaut crews from the effects of an SPE” (9).

1.1.2 Sleep-wake cycle

Another factor besides microgravity to consider is the altered circadian rhythm. The human internal clock is located in the suprachiasmatic nucleus, and as long as we stay on Earth our circadian cycle is approximately 24 hours long, equivalent to a day and night cycle on Earth. Provided we sleep during night hours, our alertness and performance will fluctuate throughout the day, with the least alertness at 03:00-05:00 and another low between 15:00-17:00 (13). The circadian fluctuations

become much less predictable once other factors are considered, e.g. our sleeping habits. If our activities no longer correspond to the physiological circadian rhythm, it can lead to medical symptoms, among others being sleep disruption, malaise, performance errors, a bad mood, inefficient communication as well as a higher accident rate (13).

Circadian dysregulation becomes much more common in an environment such as space. There are several different reasons to explain the higher incidence.

One reason is the work schedule of the flight crews. In order to ensure the success of space operations, crew members have to work in shifts and as a result they are required to adjust their sleep time to their designated shift. Consequently astronauts often have to work against their physiological rhythm.

Another cause could be the altered light conditions during the missions. While a day-night cycle lasts 24 hours on Earth, the ISS (International Space Station) circles the planet once every 90 minutes, which means that day and night alternate every 45 minutes. Light intensity plays an important role for setting our biological clock. Therefore the new 90 minute cycle represents a disruption in circadian regulation. Additionally light intensity can change during day and night phases as well, with a range of 10-80000 lux (13).

Microgravity is also discussed as a possible factor. Several effects caused by the absence of a strong gravitational field could influence sleep quality, among others the fluid shift, the back pain and the absence of pressure on the body (13).

Other factors to be considered are isolation, motion sickness, ambient temperature change, spacecraft vibrations, elevated CO_2-levels and cosmic radiation (13).

Space agencies try to combat this issue by administering light treatments before every mission in order to prevent circadian dysregulation. The treatments seem to be somewhat successful, as the subjects reported better sleep quality during the day and alertness during night shifts (13). However, the problem has not been solved completely and further research is necessary.

As a result of the dysregulation some people experience severe sleep deprivation, shifting from ground-based 8 hours to approximately 6 hours of sleep, in some cases even less than 4 hours (13). Taking into account the work schedule, the sleep deprivation combined with a night shift can present itself as a big obstacle when it comes to performance and efficiency. It can affect neuromotor functions as well as have neurobehavioral effects. Consequently there can be an impairment of coordinated movements, cognitive processes and memory, attention and reaction times (13).

Table 2: Physiological and psychosocial effects of spaceflight (14)

Physiologic effects	Launch	Duration of flight				Landing	Postflight period		
		24 h	48 h 2 wk		> 1 mo		24–48 h	1–2 mo	> 1 yr
Fluid redistribution	• Redistribution of fluid to the torso and head • 10% decreased fluid volume in the legs	• 17% reduction in plasma volume	• Gradual decrease in erythropoietin secretion, leading to a 10% decrease in total blood volume			• Orthostatic hypotension from pooling of fluids in the legs	• Return of normal fluid distribution		
Neurovestibular effects	• Space motion sickness					• Space motion sickness			
Muscle changes		• Gradual decrease in muscle mass by 20%			• Gradual decrease in muscle mass by 30%	• Muscle soreness and tightness		• Full recovery of muscle mass and strength	
		• Gradual decrease in muscle strength (up to 50% loss observed)							
Bone demineralization		• 60%–70% increase in calcium loss (urinary, fecal). Reduced parathyroid hormone and vitamin D production.							• Complete or almost complete restoration of bone density
		• Gradual loss of bone density (1%–2% per month)							
Psychosocial effects	• Fatigue, sleep debt, isolation, emotional effects, stress to the astronaut's family, multicultural crew environment								
Immune dysregulation		• Possible reactivation of latent herpes viruses and impairment of cell-mediated immunity				• Numerous cellular and other changes leading to impaired immunity		• Gradual improvement in immunity (days to weeks)	

1.1.3 Psychological effects

The previously mentioned conditions in space have mostly been directly somatic, having an influence on the human body and its functions. Psychosocial changes on the other hand have an effect on the mind and therefore affect the body indirectly. There are several environmental factors one must consider that can impact the human psyche.

Space is one of the most hostile environments known to mankind. Apart from microgravity this is mostly due to a combination of isolation, confinement and extreme conditions of the environment. Researchers have gone to great lengths to try to understand the behavioral, psychological and sociological changes that can occur through exposure to such an environment.

According to Palinkas one can divide all related aspects into three categories: individual, interpersonal and organizational difficulties (15).

Individual aspects are all connected to stress associated with the environment. Due to the remoteness of space, the isolation and confinement present a lot of challenges to consider. One such challenge is the communication with the outside world. Many people involved in manned space missions have friends and families they leave behind, which presents a great strain on everyone involved. In order to minimize this strain mission members get the opportunity to teleconference with their families. On the ISS, the astronauts are provided with an IP phone, with which they can call their families and social contacts whenever they want (16). In addition they have

regularly scheduled teleconferences with their loved ones (16). Recently another way to communicate with the outside world has been on the rise: blogging. Mission members are encouraged to write down their thoughts during their assignment, whether in journals or blogs. The latter offers the advantage of giving other people valuable insights into the state of mind of the blogger (17).

Isolation and confinement have also been shown to affect the mood. Numerous studies have reported several negative effects including depression, insomnia, irritability, anxiety and fatigue (15). However, evidence in this area has been contradictory until now, as there have been several studies showing either an absence of these negative effects or even some positive results in individual members (15). Overall the prevalence of mood disorders due to a prolonged stay in an isolated environment seems to be a matter of individual susceptibility and coping mechanisms (15,17).

The individual domain also plays a role in the selection process of astronauts. Apart from being well educated and in top physical condition, every astronaut applicant must undergo a psychiatric evaluation. Applicants with possible psychiatric conditions are excluded from the list of potential candidates, a process referred to as “select-out” (4,15,18). The remaining candidates are subjected to rigorous training and further tests. While “select-out” had the purpose of excluding applicants with psychiatric risks, the second battery of tests (“select-in”) is designed to determine who gets selected by relying on psychological criteria (19). Candidates are selected partially by evaluating their personality traits, whereby each trait is categorized into one of three groups (15).

“Right stuff” traits are goal orientation, interpersonal warmth and sensitivity, striving for excellence and the desire to do a good job. In contrast, “Wrong stuff” traits consist of arrogance, hostility and competitiveness. A third group called “No stuff” has traits like self-subordination, verbal aggression as well as being subservient (15).

In an effort to counteract some of the psychological problems associated with a prolonged stay in space, space agencies have adopted extensive programs designed to promote both psychological adaptation and behavioral health (15). Apart from the psychiatric and psychological selection process, NASA has developed the Behavioral Health and Performance Program at Johnson Space Center in Houston, Texas to provide sufficient preparation and support for future manned missions. In order to promote behavioral health astronauts receive training in behavioral medicine and during the progression of the mission they are routinely monitored with available medical and social support and intervention standing by (15). They also attend regular private medical conferences. Astronauts undergo further pre-flight training to maximize their psychological adaptation, which is also boosted by providing in-flight leisure activities and means of

communication as well as a family support office and post-flight debriefing to discuss any potentially unresolved issues that may have arisen during the mission (15).

However, not only are the members of space missions struggling individually with their situation, but they can come into conflict with each other as well. Interpersonal issues are associated with social tensions due to the environment as well as the mismanagement of the mission due to poor leadership and the hostile interaction with the ground crew (15).

The social tension resulting from living in a confined space with several other people for a prolonged period of time was reported both in space and analog environments on Earth (15). It manifests itself through increased antagonism towards other crew members or mission control, and as a result group cohesion may be lowered. However this social tension does not arise in every mission, as there have been several reported missions that were completed without any similar incidents (15). A big influence in the amount of social tension is the social, cultural and personal background of crew members as well as the cultural climate in the living quarters (15).

The crews of such missions are usually multinational, whereby individual members are often the only representatives of their respective nations. As a result the different languages and cultures can often lead to conflict between group members. However, this does not necessarily have to be the case. In some missions, crew members bonded over their shared interests, situation or views.

This phenomenon can lead to the creation of a microcultural environment, where several mission members form a group based on their similarities and as a result interpersonal relationships become less difficult. As a downside, individuals who fail to abide by the group´s rules or opinions can get ostracized from the other crew members (15). In other instances several different subgroups were formed instead of a single core group (15). This group division may become more likely the more diverse the crew is, as the increase in differences in individuals often lessens the chance of the formation of a single group with shared values and experiences (15).

While the background of each individual is important for the work climate in a confined space, the most important of them all is the mission leader. The appointed mission leader has to be task-oriented, he or she has to have a goal and be able to coordinate others towards achieving that goal. The leader is also required to be able to adapt to both the situation and to his or her crew and sometimes make split-second decisions on behalf of the other members. A person lacking some of these qualities could cause great damage, lower the morale and lead to task-disruption (15). However there is also a supportive leadership one must consider, which is not quite official but nevertheless important. A supportive leader helps other crew mates by being there for them. Sometimes this can amount to nothing more than listening to their problems. The supportive leader

does not necessarily need to be the officially appointed leader, and he also has significant impact on the working climate and the success of the mission (15).

Another important interpersonal issue to consider is the interaction between the crew and the ground crew. On several missions, the communication between those two parties has been less than amiable, largely due to misunderstandings and miscommunication. Astronauts sometimes perceived ground crews to be misinformed on the situation and therefore making unreasonable demands, whereas the ground crew found the astronauts to be lazy (15). In one instance, the crew aboard the spacecraft staged a mutiny and cut themselves off from all communications for an entire day (20). A possible explanation for such behavior could be that as outsiders who do not share the astronauts´ hardships, ground crews are used as outlets for hostility and aggression by the crew (15).

A third group of problems arise from the fact that there are many different space agencies and each agency has its own set of rules of conduct and practices regarding operating procedures. They also have different experiences regarding the application of those rules. In the case of joint space missions, one must consider the organizational differences between the space agencies to minimize the probability of failure (15).

Manned missions to space focus mainly on the international Space Station for now. As the name suggests, there are many different nations represented on the station and only limited space, meaning that every crew member has to be tolerant regarding fellow crew members and their potentially different cultural background. In order to ensure the smooth operations of any mission, members are selected very carefully from potential candidates (4). The goal is to maximize group cohesion, e.g. by joint birthday celebrations (21).

Many crew members in space have families and entering a space program can present a great strain for the entire family, due to the extensive training before any mission and the separation accompanied with it. Space agencies try to combat this issue by providing family support programs and organizing teleconferences between the crew and their families. This factor may become even more important as the agencies go into the future, specifically for a manned mission to Mars (4).

Depression and anxiety have also been observed in some cases shortly after launch, which can be attributed to becoming accustomed to the new environment or a feeling of insignificance of one´s own or Earth´s existence. Isolation and confinement to a small space may also play a role (22).

1.2 Ground-based models of simulating psycho-physiological conditions of spaceflight

In order to improve our understanding of the impact of gravity as well as being a part of

astronaut training, space agencies worldwide conduct research projects striving to simulate conditions in space and to understand their ramifications. However due to the complexity of such an environment, it is currently impossible to simulate all the contributing factors at once. As a result, there is a wide variety of experiments conducted in this area.

1.2.1 Simulating microgravity

When it comes to microgravity research, the only alternative to actually going into space is to try to simulate near-weightlessness. This endeavour is essential for both financial and security reasons. There are several different approaches depending on the research goal.

Studies involving cell cultures, plants or animals use devices that inhibit the perception of gravity through rotational movements, which enables researchers to monitor the resulting changes in the cells or organisms. One of the most prominent devices is the 2D-clinostat, which rotates the samples around a single axis. The random positioning machine, sometimes referred to as the 3D-clinostat, adds a second rotation axis and further inhibits any influence of gravity. The principle of rotation is also used in rotating wall vessels, which are mainly used in cell culture experimentation (23). However there is another method called diamagnetic levitation. It uses a strong magnet to counteract gravity in diamagnetic materials such as water or even small animals like frogs (23).

Figure 2: Microgravity Simulation; Top left: Wall Rotating Vessel (24); Top right: Fast rotating 2D clinostat (24); Bottom left: Random Positioning Machine (24); Bottom right: Diamagnetic Levitation (24)

Human research on the other hand is mainly done to simulate the physiological changes in space due to microgravity, most importantly the fluid shift and loss of muscle strength and bone density. Those effects are usually produced by either lying in a head down tilted bed or water submersion as well as parabolic flights for short-term experiences of weightlessness (25).

The principle of the head-down-tilt is very straightforward: The subject spends several days in bed with a head down tilt of 6 degrees. The bed rest causes the muscles to atrophy (26), while the head down tilt leads to decreased bone density (26) as well as a fluid shift towards the upper body, thereby mimicking the effects of microgravity (27). By measuring and monitoring the effects of simulated microgravity, researchers were able to come up with a training regimen designed to keep astronauts healthy during their stay on the ISS. One such exercise involves running on a treadmill with a graded lower-body compression suit with 100 mmHg negative pressure applied to the lower body (28). The negative pressure helps counteract the head ward fluid shift by essentially sucking some of the volume back into the lower extremities.

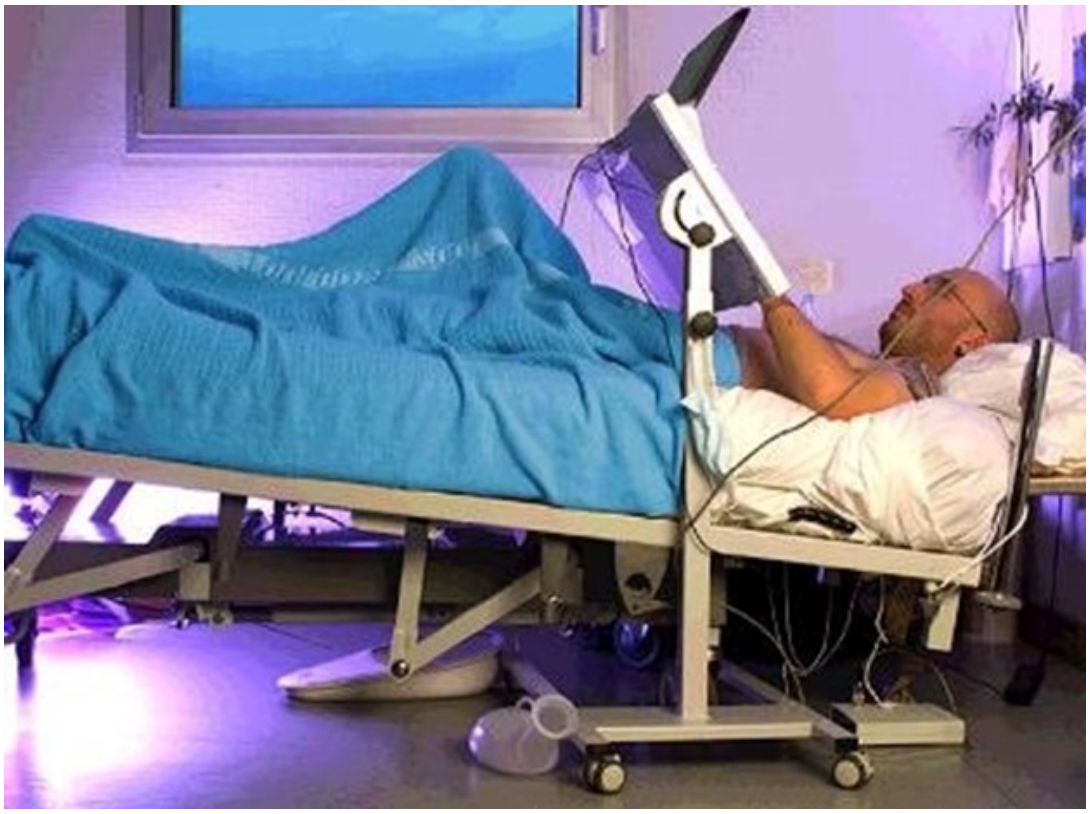


Figure 3: 6° Head Down Tilt Bed Rest (29)

A different approach to simulated microgravity is water immersion. This method is mainly used to train astronauts in regard to EVA walks and currently there exist two main facilities worldwide responsible for this stage of training: NASA's Neutral Buoyancy Laboratory at Johnson Space Center in Texas and the Gagarin Cosmonaut Training Center in Russia (30).

The subjects put on slightly modified pressure suits and are lowered into the water together

with the equipment necessary for the training session. Additional divers add weight to the subject and thereby counteract the buoyancy in the water. As a result they achieve a state of neutral buoyancy and can simulate EVA tasks (30). The main purpose of such exercises is to learn to move objects slowly and carefully.

As with head down tilt experiments, neutral buoyancy has a few drawbacks. For one, the subject can still feel the gravitational pull, and consequently he or she is leaning against the surface of the suit that is facing down (30). Additionally the subject experiences significant drag in the water, making the movement of objects underwater very difficult (30). In contrast, due to microgravity it is very easy to move in space and quite hard to keep objects still. To account for that discrepancy between the water and the space environment, the goal is to move slowly and thereby minimize the amount of drag (30).

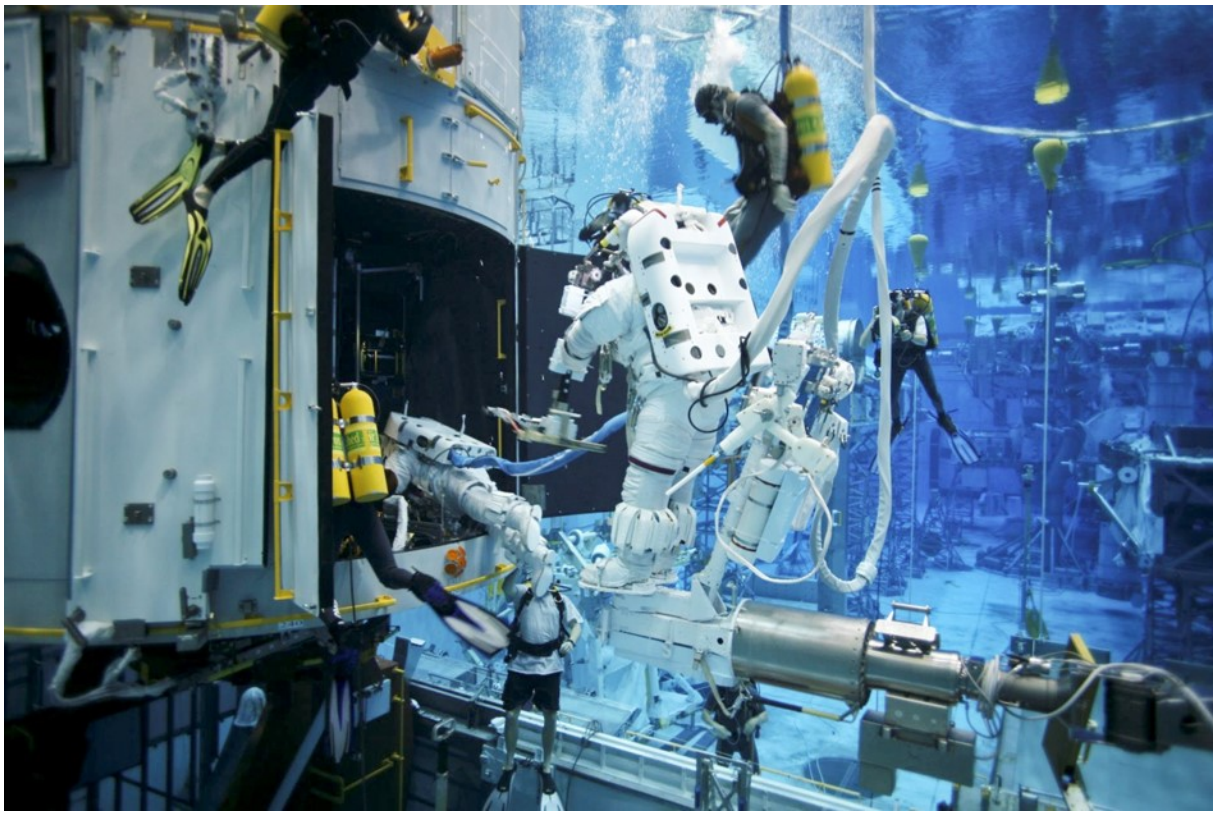


Figure 4: Water Immersion Experiment at the Neutral Buoyancy Laboratory (31)

The third microgravity simulation method consists of a series of parabolic flights which result in a few seconds of free fall shortly before, during and after reaching the peak altitude of each parabolic flight path (32). This method offers the opportunity to experience the same sensation of free fall as in orbital spaceflight.

Because of the short duration of the simulated microgravity, it is not possible to conduct long term studies with parabolic flights. Space agencies use all three methods and combine the results to get a comprehensive overview of the effects of simulated microgravity.

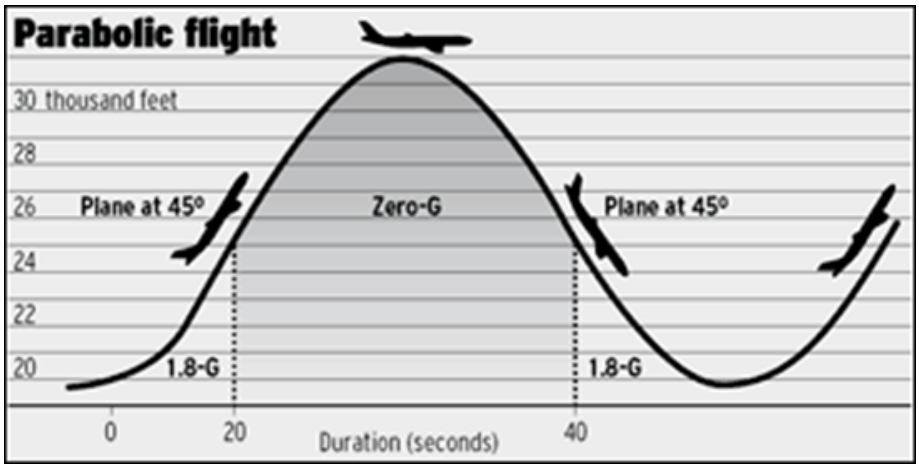


Figure 5: Parabolic Flight Path (33)

1.2.2 ICE environments

While simulated microgravity mainly gives insights into the physiological changes and adaptation of the human body, the psychological aspects of spaceflight play only a minor role in these experiments. As it is impossible to create an environment identical to space on Earth, research has been done in environments as close as possible to space. Such environments offer isolation, confinement, extreme conditions or a combination thereof and therefore they are referred to as ICE environments.

While some research focuses on the testing of the equipment and therefore requires rocky or desert terrain to simulate the surface of Mars or the Moon like NASA's Desert Research and Technologies Studies (Desert-RATS) (34), other experiments like the Pavilion Lake Research Project in Canada (35) or NASA's Extreme Environment Mission Operations (NEEMO) in Florida take place underwater. In the case of NEEMO the astronauts, engineers and researchers spend up to three weeks in an underwater research station named Aquarius (36).

Most analog environments on Earth serve to calibrate and adjust the equipment and are therefore only short term. In order to research the long term psychology of spaceflight, the duration of the experiments needs to be much longer than two to three weeks. A first step in that direction was the Mars 500 Mission, where in the final stage a group of six people (three Russians, one Frenchman, one Italian and one Chinese citizen) lived together in isolation for a period of 520 days to simulate a trip to Mars. The subjects had a limited supply of consumables and were hermetically

isolated from the outside world. The communication was delayed by 25 minutes to simulate time lag over vast distances (37).

An even better ICE environment can be found at the South Pole. In Antarctica there are many factors similar to space, especially in the interior of the continent, in extremely remote regions. Currently there are only three manned research stations in the interior of the continent (US-Station Amundsen-Scott, Russian Vostok-Station and the European Concordia-Station) that operate during the winter (38), and of those three, Concordia is the station currently used by the ESA to research the psychological effects of a long term mission in an ICE environment (39).

1.2.3 Concordia

Concordia Research Station is located in the Australian Sector of Antarctica, with the nearest coastline being over a thousand kilometers away. It was finished in 2005 as a joint French-Italian project at approximately 3200 meters above sea level and serves as a base of operations for several scientific studies, including environmental, geomagnetic and glaciological research, as well as human biological, meteorological, seismological and astronomical observations (40).

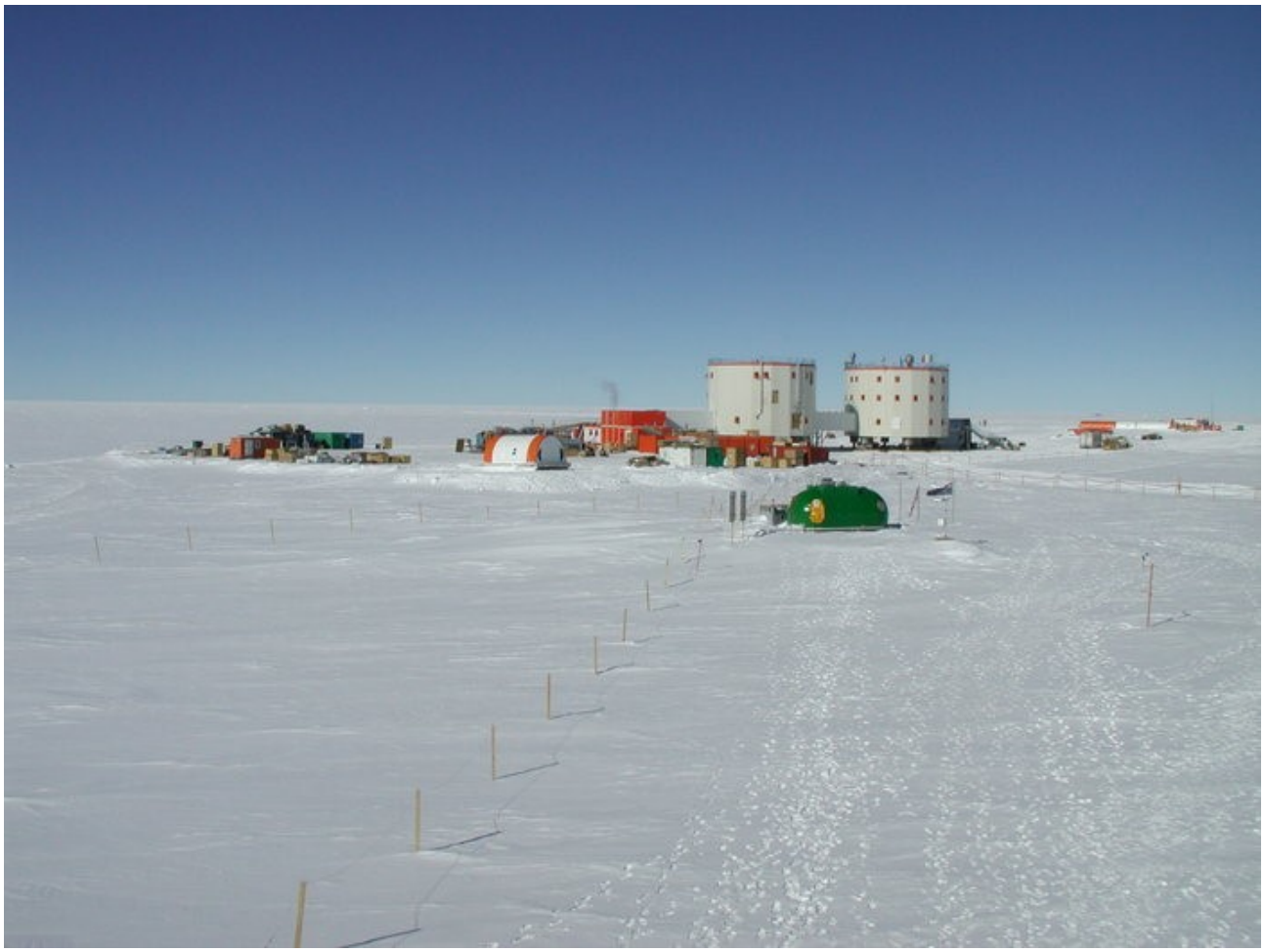


Figure 6: Concordia Research Station (41)

The station offers several advantages compared to other space analogs on Earth as it is the very epitome of an ICE environment on Earth. The nearest human settlement is the Russian Vostok Research Station at a distance of 560 kilometers and there is no wildlife in the vicinity of the station, making it extremely isolated and remote (42). With an average temperature of minus 50 °C it is one of the coldest places on our planet, during the winter months temperatures can reach even minus 80 °C.

Accessibility is also greatly influenced by the seasons. In the summer months, the sun never sets and the crew consists of a few dozen personnel. Planes arrive frequently with new supplies. In the winter months (May-August) the sun never rises and temperatures drop significantly. At minus 80 °C brake fluid and even fuel becomes solid, making the station unreachable. As a result, the winter crew of 12-15 people is on their own for nine months (February-November), with no outside help available (43).

These analogies to space make Concordia Station very interesting for the European Space Agency, and each year they send a doctor to Antarctica to run experiments and observe his or her fellow team members. The team members are composed of a wide variety of nations and professions, as there are many different projects and experiments going on at the same time. Among the crew is the technical team with a plumber, mechanic and a chief, a glaciologist, astrophysicist, electrician, meteorologist, an IT & Communications expert as well as a chef and the medical team, composed of the station doctor, a nurse anesthetist and if the position is separated from the station doctor an ESA research doctor (44). Everyone has a vital role to play if the group is to make it through the isolation unscathed.

The station stays in contact with the outside world and mission members are able to blog about their experiences, which give further insight into their state of mind. Here is an excerpt from the blog of Alexander Kumar, the station doctor and ESA research doctor of the 2012 winter-over team, written in the midst of winter in Concordia: “We hit a high crescendo with midwinter celebrations, but the road ahead looks long and icy. The real test is yet to come. We have to remain a team. Only a team can survive in such extreme conditions. Everyone has their crucial role on the base.” (45)

There are three main stressors during the mission itself: The ICE environment with long term isolation, confinement and extreme conditions like the cold, the circadian dysregulation due to the extreme seasonal changes of permanent day or night for months at a time, and the high altitude, leaving the mission members in a constant state of hypoxia (46).

For ESA the mission serves to answer several questions regarding group behavior: Are the

mood changes and group cohesion over a longer isolation period associated with hormonal, hemodynamic and/or autonomic adaptation? What is the connection between circadian dysregulation, mental fatigue and sleep loss, and can they be predicted through measurements of peripheral temperature or urinary melatonin? If so, how does our body adapt to the environment over time? If there are any hemodynamic changes, how are they affected by the long term exposure and isolation? Are there any differences to the Mars 500 Mission? How does the autonomic nervous system work under the extreme conditions there? The last question is especially important for the purpose of this DA.

1.3 Assessment of physiological and psychological functions

Up until now, this thesis has explored the various hazards and factors of spaceflight and analog environments. Subsequently it will explain the physiological process related to the data of Concordia as well as the necessary equipment required to measure it. In order to monitor the subjects during a prolonged period of isolation, the doctor needs to use the equipment available at the station. Therefore there are several requirements the test equipment has to meet in order to be usable in Concordia. It has to be light, user-friendly and easily operable. Due to stress-related research, the measurements have to be minimally stressful and non-invasive to the subjects, all of whom are volunteers. As a result, they amount to Actigraphy, Psychomotor vigilance tests, Posture evaluating platform, saliva and urine samples as well as the ChronoCord, responsible for measuring the beat-to-beat heart rate variability.

1.3.1 Heart Rate Variability

The human heart is unique in its ability to create a cellular action potential without the input of neurons. The sinoatrial node located in the right atrium gives off about 100 action potentials per minute on its own (47). However, while the heart does not need neurons to contract, it does need neural input to regulate cardiac activity depending on how much oxygen is needed in the system (48). That is why the heart rate is regulated by the Autonomic Nervous System (ANS) which can be divided into two counterparts.

The sympathetic nervous system (SNS) innervates the heart from the thoracic spinal segments Th1-4, and it is responsible for increasing the cardiac output by secreting adrenaline/epinephrine and noradrenalin/norepinephrine (47). They affect the β1-adrenergic receptors in the cardiac muscle and speed up the sinoatrial node as well as improve the contractility

of the myocardium through intracellular calcium concentrations. The conducting speed of the atrioventricular node (AV node) is also increased (47).

The counterpart of the sympathetic nervous system is the parasympathetic nervous system (PSNS), which innervates the heart muscle via the vagus nerve. By releasing acetylcholine, it decreases cardiac output via the M2-muscarinic receptors (47).

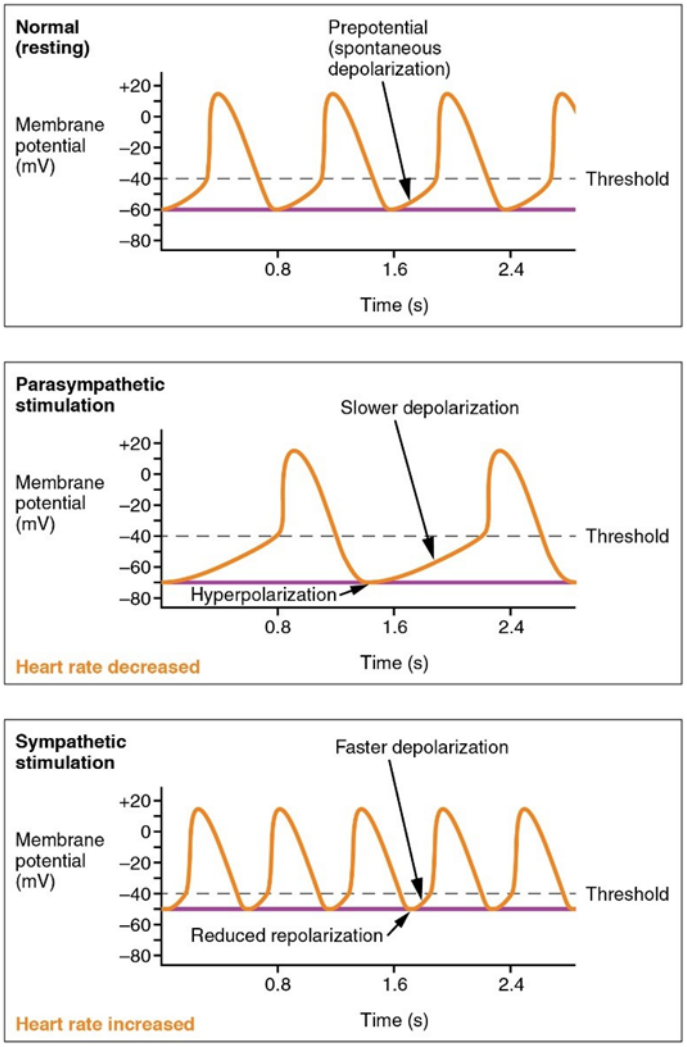


Figure 7: Effects of Parasympathetic and Sympathetic Stimulation on Normal Sinus Rhythm (49)

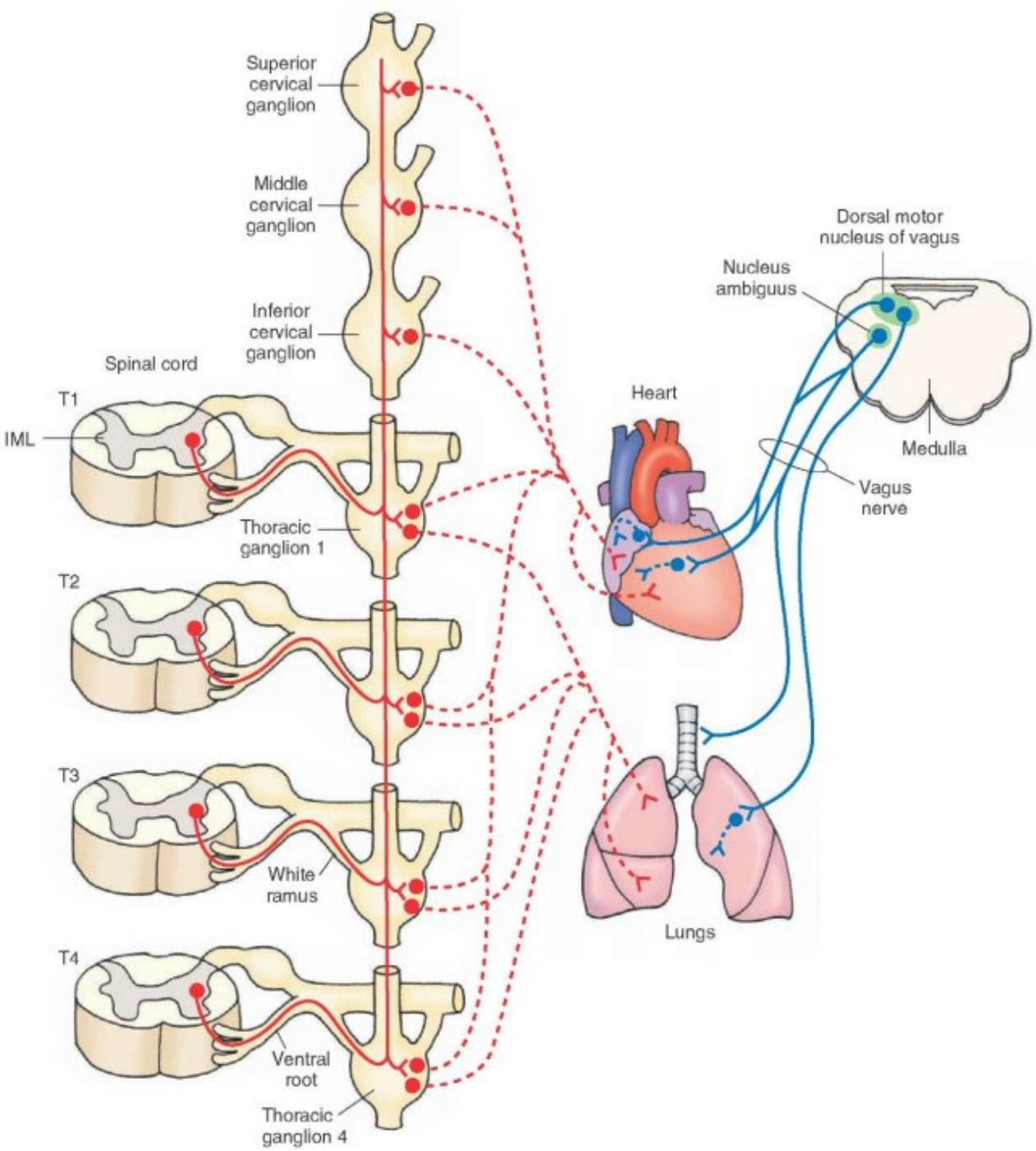


Figure 8: Cardiac Innervation by the ANS (50)

Most of the time, the SNS and PSNS are in a state of balance, leading to a heart rate of 60-100 in an average human. Due to the constant input, the beat-to-beat duration varies slightly, with each heartbeat being somewhat slower or faster than the previous heartbeat. This difference in the RR-interval is referred to as heart rate variability (HRV) (51).

There are several factors which influence the ANS and thereby the HRV. Those influences can be divided into four different frequency bands which affect the HRV at certain intervals.

The first frequency band is the high frequency band (HF band). Its frequency range is 0,15-0,4 Hz and it represents the respiratory sinus arrhythmia (RSA), a phenomenon describing heart rate fluctuations depending on our respiration (52). When an intake of air occurs, the thorax expands and the additional negative pressure dilates the blood vessels. Due to the Frank Starling mechanism, by decreasing the peripheral resistance the heart rate increases to regulate blood pressure. The opposite happens during exhalation. The thorax decreases in volume, and the additional pressure compresses the thoracic blood vessels, and as a result the heart slows down.

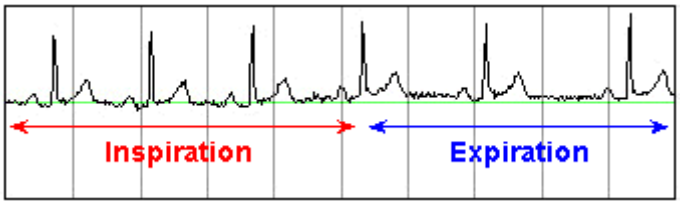


Figure 9: Respiratory Sinus Arrhythmia (53)

The low frequency band (LF band) is another factor group which modulates the heart rate. The main purpose of this fluctuation is blood pressure control through baroreceptor fine-tuning. Baroreceptors are sensitive to the stretching of the blood vessel walls they are located in, and they are activated through the dilatation of those walls. They are found in the heart chambers, Venae cavae, the aortic arch as well as the carotid sinuses. When they are activated, a signaling pathway relays the action potentials of the receptors to the Nucleus of the solitary tract, which in turn stimulates the vagus nerve and reduces the sympathetic output, decreasing the heart rate. The more extensive the stretch of the blood vessel walls, the more active the baroreceptors become, and the more the heart rate decreases as a result, thereby counteracting the increased blood pressure (52). The LF band is therefore a result of both sympathetic and parasympathetic nerve fibers.

This feedback loop between the heart and the brain oscillates at a frequency of approximately 0,1 Hz, and consequently every ten seconds the heart rate gets readjusted for blood pressure regulation, thereby influencing the HRV (52).

While HF and LF bands have been thoroughly researched and linked to definitive causes, the other two bands are much less understood. The very low frequency band (VLF) ranges between 0,0033 and 0,04 Hz and it has the highest association with all-cause mortality (52). The exact mechanism is still unknown, however, it has been shown that this particular band is intrinsic to the heart and plays a vital role in its nervous system (52). A reduction of VLF amplitudes is highly correlated with highly increased mortality in animal subjects (52).

All oscillations with a frequency below 0,0033 Hz are categorized as ultra-low frequencies

(ULF). With a period over five minutes, this frequency band is mostly left out of HRV measurements due to the recommendations of the task force of 1996 which suggested dividing up 24-hour measurements into 5-minute segments and measuring the values of each segment before calculating the mean values for the entire duration of the measurement (52). As a result ULF has been mostly ignored and their effect has not been discovered so far (52).

Apart from the above mentioned periodic changes of the HRV, the balance between the SNS and the PSNS can also change due to other circumstances like physical activities. The SNS is activated in times of physical exercise and can affect HRV for hours at a time, while rest and sleep promote parasympathetic nervous input (54). In long term measurements, long term circadian regulation may as well be responsible for up to 95 percent of the total HRV, with only five percent being attributed to HF/LF frequency bands (51). Thus, HRV fluctuates heavily as part of a circadian cycle (55).

1.3.1.1 Clinical relevance

HRV has established itself as an indicator for ANS activity (52,54). As a result it is used in numerous studies to indirectly measure sympathetic and parasympathetic function. Most commonly it is used as a prognostic factor for the mortality and prognosis of patient with chronic heart failure, as it has been shown that a reduced HRV is associated with a higher probability of fatal outcomes (56). A reduced HRV has generally been linked to all-cause mortality, autonomic neuropathy in diabetes patients (55)(54)(53)(52)(51)(50)(49), autonomic dysfunction resulting in anxiety, depression and asthma, as well as an indirect predictor of future health problems, including myocardial infarction (52,55). One possible explanation that is supported by evidence suggests that HRV correlates with autonomic regulation, adaptation and balance. Any problems leading to a disruption of ANS function also leads to a reduced HRV (52). It is also seen as an indicator for the overall adaptive capabilities of the ANS, which might explain why patients with hypertension have reduced baroreflexes and HRV (52).

1.3.1.2 Measuring HRV

Autonomic function can be measured via photoplethysmography, which measures the pulse rate variability or via an ECG, in which case the HRV is measured (57). As this study used HRV as a parameter for autonomic function, I will only focus on ways to measure HRV.

There are two different approaches to measuring HRV. One focuses on the absolute time differences between the individual beats, the time domain. This time domain has several parameters for both short- and long-term measurements.

One of the simplest parameters of time domain detection is the standard deviation of normal-normal intervals (SDNN). It is a non-specific parameter for the overall HRV, without any clues as to the autonomic pathways or the origins of the variability (58). Another limiting factor is that the SDNN correlates with the measurement length, which is why studies which used SDNN to determine any effect or influence of or on HRV should standardize their measurement duration protocols in order to eliminate this bias (51).

A modified parameter of SDNN is the SDANN value, which is the standard deviation of the average NN intervals over short periods of time, usually five minutes. Other parameters are NN50, the number of neighbouring NN intervals with a difference of more than 50 ms, RMSSD, the square root of the mean value of the sum of squared differences between adjoining NN intervals, the SDNN index, which is the mean of SDNN values calculated for each 5-minute segment of the measurement, and there are many others, which can be seen in the table below (51).

Table 2: Selected Time Domain Measures of HRV (51)

Variable	**Units**	**Description**
Statistical Measures		
SDNN	ms	Standard deviation of all NN intervals
SDANN	ms	Standard deviation of the averages of NN intervals in all 5-minute segments of the entire recording
RMSSD	ms	The square root of the mean of the sum of the squares of differences between adjacent NN intervals
SDNN index	ms	Mean of the standard deviations of all NN intervals for all 5-minute segments of the entire recording
SDSD	ms	Standard deviation of differences between adjacent NN intervals
NN50 count		Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; three variants are possible counting all such NN intervals pairs or only pairs in which the first or the second interval is longer
pNN50	%	NN50 count divided by the total number of all NN intervals
Geometric Measures		
HRV triangular index		Total number of all NN intervals divided by the height of the histogram of all NN intervals measured on a discrete scale with bins of 7.8125 ms (1/128 seconds)
TINN	ms	Baseline width of the minimum square difference triangular interpolation of the highest peak of the histogram of all NN intervals
Differential index	ms	Difference between the widths of the histogram of differences between adjacent NN intervals measured at selected heights (eg, at the levels of 1000 and 10 000 samples)[20]

Variable	Units	Description
Logarithmic index		Coefficient φ of the negative exponential curve $k \cdot e^{-\varphi t}$, which is the best approximation of the histogram of absolute differences between adjacent NN intervals

The second way to measure HRV is by looking at the various frequency bands (see above) within the overall HRV. This approach is referred to as the frequency domain and it uses parametric and nonparametric mathematical algorithms to define the frequencies composing the HRV (51). An overview of frequency domain parameters can be seen in table 3.

Table 3: Selected Frequency Domain Measures of HRV (51)

Variable	Units	Description	Frequency Range
Analysis of Short-term Recordings (5 min)			
5-min total power	ms^2	The variance of NN intervals over the temporal segment	≈≤0.4 Hz
VLF	ms^2	Power in VLF range	≤0.04 Hz
LF	ms^2	Power in LF range	0.04-0.15 Hz
LF norm	nu	LF power in normalized units LF/(total power−VLF)×100	
HF	ms^2	Power in HF range	0.15-0.4 Hz
HF norm	nu	HF power in normalized units HF/(total power−VLF)×100	
LF/HF		Ratio LF [ms^2]/HF[ms^2]	
Analysis of Entire 24 Hours			
Total power	ms^2	Variance of all NN intervals	≈≤0.4 Hz
ULF	ms^2	Power in the ULF range	≤0.003 Hz
VLF	ms^2	Power in the VLF range	0.003-0.04 Hz
LF	ms^2	Power in the LF range	0.04-0.15 Hz
HF	ms^2	Power in the HF range	0.15-0.4 Hz
A		Slope of the linear interpolation of the spectrum in a log-log scale	≈≤0.04 Hz

2 Aims and Objectives

The main purpose of this thesis is to analyze the effects of the extreme environment on the vegetative function of the winter over team of 2012 at Concordia station.

The main question to answer is how the combination of extreme isolation, hazardous environment and hypobaric hypoxia at a height of approximately 3200 meters above sea level affects autonomic nervous system function. How does it affect the subject´s health and performance? Specifically this thesis focuses on how ANS function changes over time in the same individual. In this case another important topic is whether and in what way the photoperiodicity adversely affects the body´s circadian rhythm.

The answering of these questions could provide valuable insight for future space exploration. The more we know about behavioral and physiological changes as a means of adaptation, the more prepared we are for long duration space missions like the exploration of Mars.

The expectation for this study was that the combined stressors at Concordia would shift the autonomic balance and promote sympathetic excitation, leading to decreased HRV parameters. I also expected them to worsen over time, correlating to their exposure time to the environment.

In Concordia HRV was used to indicate ANS function, as it is easily measurable through non-invasive means.

3 Methods and Measurements

The station doctor of the winter over team of 2012, Alexander Kumar, measured HRV through the use of the ChronoCord®, a light, portable, single-channel long-duration ECG device. It was developed by the Human Research Institute (HRI) located in Weiz, Austria as a way to reliably detect the smallest differences in beat to beat intervals. The ChronoCord® measures the heart rate with a sampling rate of 8000 Hz, it stores the information automatically on an imbedded MicroSD-card and is run by a standard AA battery.

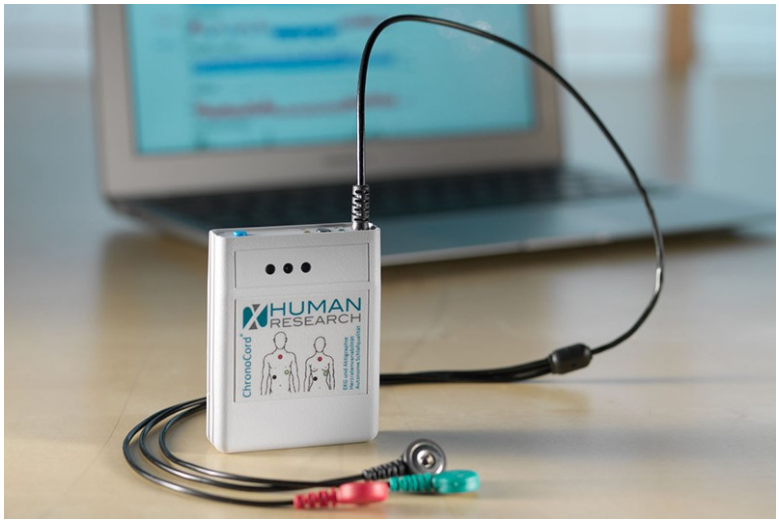


Figure 10: ChronoCord Device (59)

The raw data is extracted and stored on a computer with a program also developed by the HRI. Once extracted, information from each measurement date is saved in three different data formats. The edf-file contains the original ECG. The difference in beat to beat intervals is stored in the separate fif-file and the third acc.edf-file stores sudden spikes or decreases in the heart rate and is therefore a good indicator for movement.

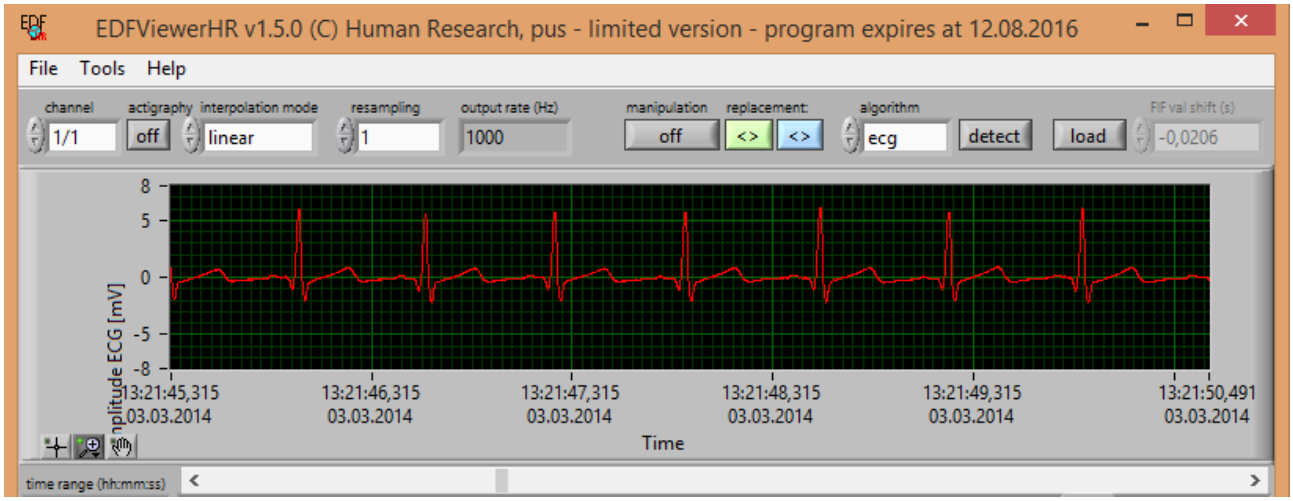


Figure 11: Original ECG of the Measurement stored in the edf-file; © Human Research Institut,

Weiz, www.humanresearch.at

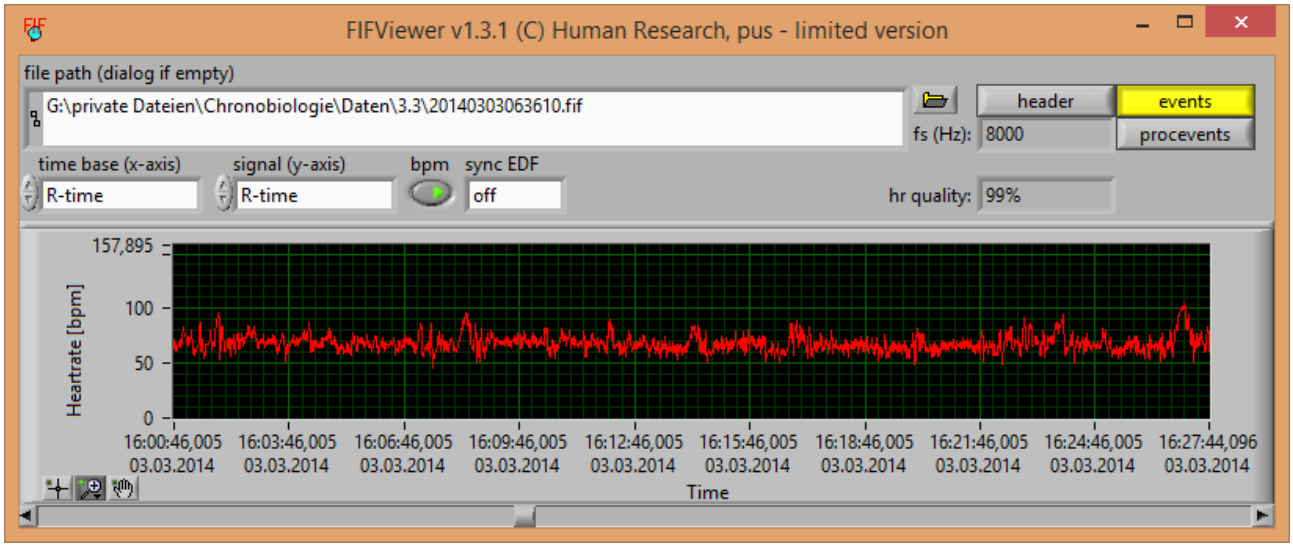


Figure 12: HRV Data stored in the fif-file; © Human Research Institut, Weiz, www.humanresearch.at

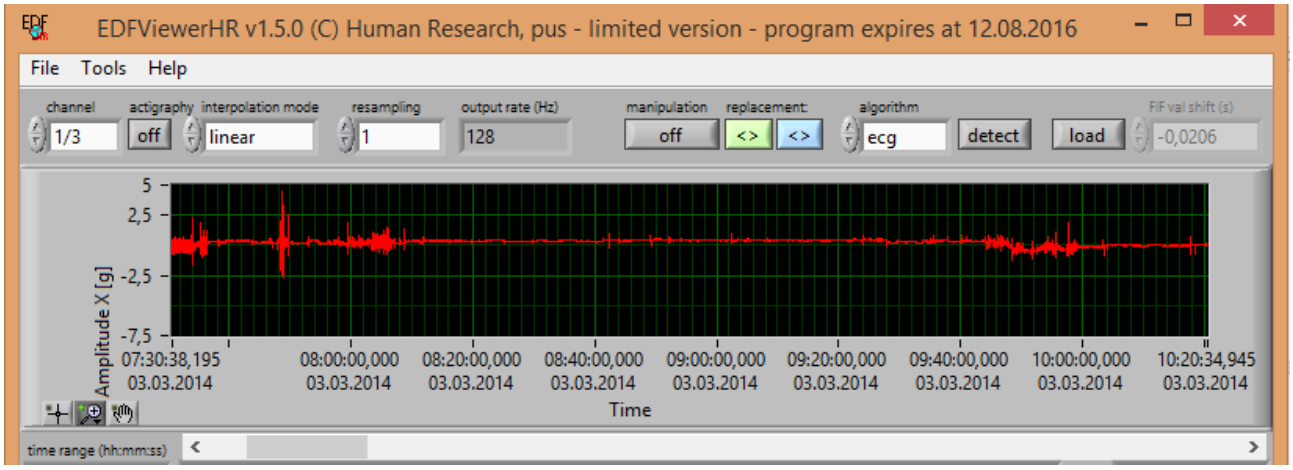


Figure 13: Movement Data stored in the acc.edf-file; the more the subject moves, the more the recording oscillates (in this case around 08:00 and between 09:40 and 10:00; © Human Research Institut, Weiz, www.humanresearch.at

The subjects can perform their daily routine without any hindrance from the measurement. However, an important part of this process is to document one´s own activities. HRV is highly susceptible to physical activity due to orthostatic reflexes and a higher or lower oxygen requirement. As such, it is important to write down the schedule of the day. It is especially important to record one´s own sleep and wake times. Without the activity protocols, the only other way to determine the sleep phase is through backtracking the original raw data and look for sudden drops in heart rate and movement.

3.1 Taking the measurements

Out of the 12/13 people staying at Concordia for the winter months in 2012, ten people

participated in the HRV measurements. Alexander Kumar, who was both the station´s medical doctor and research doctor for ESA, took the measurements once every few weeks.

3.2 Preliminary analysis

Once the mission was completed the data was brought back to the HRI in Weiz, Austria for further analysis. Upon arrival it was discovered that the data was incomplete. Most data sets were missing the edf-file with the original ECG data and there were also no activity protocols filled out. The measurement lengths also differed greatly from one another, with some recordings being only six hours long and others containing up to 55 hours' worth of data. Many of the measurements also had periods of invalid or empty recordings, most likely due to bad electrode contact (See Table 4).

Table 4: Original data received from Concordia with basic analysis done by the HRI (Valid dur. is the duration of all valid data after the empty parts have been deducted)

Nr.	Source	Code_ID	Age	date of measurment	Start time	Duration	Valid dur.	Comments
1.	CD_A	DC802	26	26.04.2012	10:27	**55**	48	empty recording (~9h)
2.	CD_A	DC802	27	12.06.2012	08:04	**50**	50	
3.	CD_A	DC802	27	29.07.2012	12:54	**50**	50	
4.	CD_A	DC802	27	08.09.2012	11:35	**50**	50	
5.	CD_A	DC803	28	01.05.2012	11:07	**31**	25	empty recording (~6h)
6.	CD_A	DC803	28	02.05.2012	17:43	**22**	22	
7.	CD_A	DC803	29	09.06.2012	19:14	**50**	50	
8.	CD_A	DC803	29	23.07.2012	10:52	**50**	50	artifacts (ES?; electrode-contact?)
9.	CD_A	DC803	29	01.09.2012	04:44	**50**	50	artifacts (ES?; electrode-contact?)
10.	CD_A	DC803	29	03.10.2012	15:32	**50**	50	unusual HRV - artifacts (AR?)
11.	CD_A	DC804	34	15.03.2012	10:00	**50**	0	bad electrode-contact?
12.	CD_A	DC804	35	07.05.2012	09:28	**48**	19	empty recording (~29h)
13.	CD_A	DC804	35	13.07.2012	11:31	**50**	19	bad electrode-contact?, AR?
14.	CD_A	DC804	35	16.07.2012	18:12	**50**	36	bad recording/ elec. contact (~14h)
15.	CD_A	DC804	35	16.08.2012	09:52	**40**	40	unusual HRV-periods; bad recording/ elec. contact (~10h)
16.	CD_A	DC804	35	09.10.2012	10:26	**26**	26	bad recording/ elec. contact (~3h)
17.	CD_A	DC805	24	02.05.2012	04:50	**34**	28	start with bad recording/elec. contact (~5h)
18.	CD_A	DC805	24	31.07.2012	16:08	**46**	46	
19.	CD_A	DC805	24	11.09.2012	06:06	**50**	47	bad recording during 1st end of sleep/elec. contact (3h)
22.	CD_B	DC801	33	08.03.2012	09:12	**36**	36	
23.	CD_B	DC801	33	21.05.2012	09:25	**50**	50	
24.	CD_B	DC801	33	26.06.2012	13:37	**50**	50	some bad electr. cont.
25.	CD_B	DC801	33	02.08.2012	16:09	**50**	50	periods with lost electr.cont.

26.	CD_B	DC801	33	13.09.2012	14:21	**50**	50	some bad electr. cont.
27.	CD_B	DC809	41	16.04.2012	10:34	**55**	41	some AR/ES during wake; empty recording (14h)
28.	CD_B	DC809	41	14.06.2012	15:53	**50**	50	some AR/ES esp. during wake?
29.	CD_B	DC809	41	25.07.2012	18:10	**50**	45	AR/ES and some periods with lost electr. cont.
30.	CD_B	DC809	41	27.07.2012	20:58	**39**	39	no activity protocol; only ecg, hr- and acc-data; AR/ES
31.	CD_B	DC809	42	05.09.2012	10:07	**50**	50	some artifacts esp at beginning (10h); AR/ES/elect.cont.
32.	CD_B	DC809	42	11.10.2012	19:01	**50**	50	AR/ES; 3h bad elect. contact at the end
33.	CD_B	DC810	31	19.04.2012	11:47	**55**	48	empty recording (~4h) and periods w. lost contact
34.	CD_B	DC810	31	07.06.2012	11:43	**50**	45	(5h lost signal in the middle of m.)
35.	CD_B	DC810	31	19.08.2012	18:16	**50**	42	empty recording (8h); periods w. unusual HRV (RSA?)
36.	CD_B	DC810	31	21.10.2012	06:04	**50**	40	6h no signal at beginning, 4h in the middle;
37.	CD_C	DC806	30	21.03.2012	11:36	**40**	40	
38.	CD_C	DC806	31	04.07.2012	08:42	**6**	6	
39.	CD_C	DC806	31	05.07.2012	18:05	**50**	48	2h lost signal (middle)
40.	CD_C	DC806	31	07.07.2012	23:10	**16**	10	5h lost signal (middle)
41.	CD_C	DC806	31	09.08.2012	19:58	**50**	45	after ca. 3h lost signal (5h)
42.	CD_C	DC806	31	11.08.2012	12:25	**17**	17	
43.	CD_C	DC806	31	18.09.2012	14:27	**50**	50	some artif. (ES?; Elec.cont.)
44.	CD_C	DC807	55	13.04.2012	10:03	**55**	31	
45.	CD_C	DC807	55	11.05.2012	18:49	**50**	50	
46.	CD_C	DC807	55	08.07.2012	15:21	**50**	50	
47.	CD_C	DC807	55	07.08.2012	09:34	**50**	50	periods w. unusual HRV (sleep)
48.	CD_C	DC808	49	11.04.2012	07:51	**45**	28	empty recording (17h)
49.	CD_C	DC808	49	17.05.2012	07:38	**48**	43	bad elec. contact (5h)
50.	CD_C	DC808	49	22.08.2012	10:01	**50**	40	empty recording (10h)
51.	CD_C	DC808	50	29.09.2012	10:42	**50**	50	

As the missing ECG was not necessary to upload the HRV data to get the time and frequency domain parameters (see below), its absence from the files did not influence the outcome of the project greatly. The varying measurement lengths presented a bigger problem, as they made it harder to compare the measurements to each other as well as other standardized 24-hour measurements. This issue as well as the invalid periods could be solved by dividing the long measurements into approximately 24-hour measurements and cutting out most of the invalid periods. However, the missing activity protocols were harder to replace. The team at the HRI had no clue as to the activities of the subjects at any specific time, and consequently it became much more difficult to assess unusual HRV readings. The loss of sleep time data was even more detrimental, as several goals of this study were connected to circadian rhythms and their disruption.

Undeterred by this setback, the researchers at the HRI began to analyse the data for any

information they could find. The most important objective was to recover the sleep and wake times. An intern went through every fif and acc.edf file of every measurement to look for specific signs of the subject going to sleep or waking up. These were mostly corresponding drops in both heart rate variability and movement. In the few measurements where the edf file was also brought back it was also taken into account.

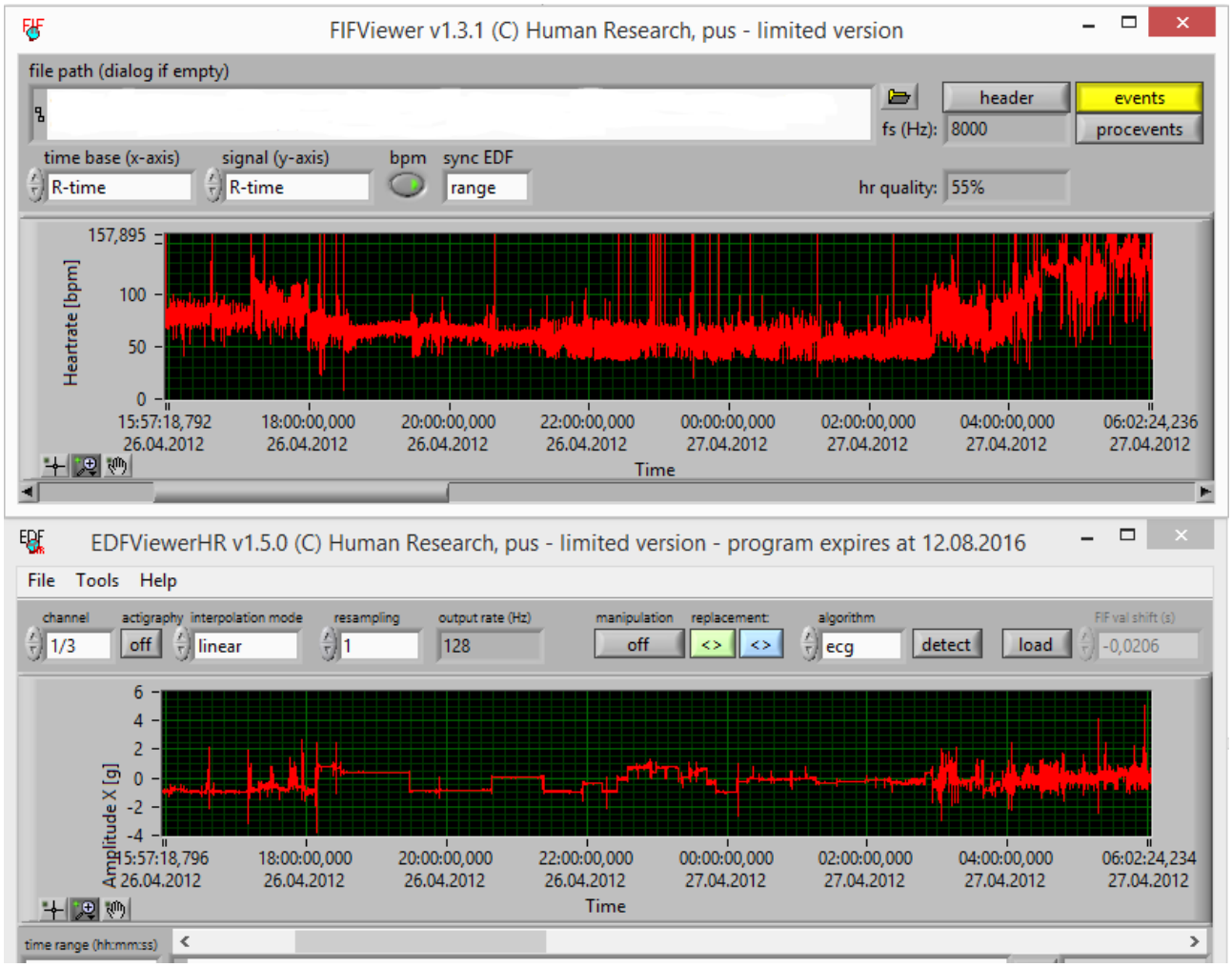


Figure 14: Example of a Sleep Phase (characterized by a sudden drop in both movement and heart rate at approximately 18:00 and an instant rise halfway between 02:00 and 04:00); © Human Research Institut, Weiz, www.humanresearch.at

At this part of the process I became involved due to this thesis. I re-examined the process of finding out the sleep and wake times and compared my findings to those of the intern. In cases where our sleep and wake times were not identically identified I consulted Mag. Vincent Grote from the institute to go over the data and with his help I completed the analysis.

3.3 Standardization of measurement data

The next step was to standardize the measurement lengths. This was necessary for two reasons: First, by maximizing standardization the measurements can be compared more reliably

with each other and ideally with other unrelated subjects who did not experience a winter over period. Second, the next step involves uploading the fif file onto the homepage of the HRI. There, the file is analyzed based on age, sleep and wake times and the results are separated into 24-hour mean values, sleep time mean values as well as wake time mean values. Those values are then compared with 24-hour measurements of the reference group in the same age range in the database. Depending on how the data is standardized, the mean values could change considerably, as could the percentile of the value in the age group.

There are also several technical restrictions connected to the upload which had to be taken into account during standardization. The program that converts the fif file into usable parameters needs a measurement length of at least sixteen hours, so any measurement with a shorter time span cannot be analyzed.

Furthermore, the program´s biggest limitation is its inability to take into account multiple sleep phases. Only one period of time per measurement can be entered as sleep, which presents a big problem considering the dramatically altered light conditions at the station. Sleep disruption can therefore be considered highly probable leading to several sleep phases.

3.3.1 Methodology of standardization

In order to address those issues, the processing procedure had to follow a precise methodology. The measurements would have to be cut into segments as 50 hours were too long for comparison. The following criteria were used to determine the cutting points:

The primary goal was to obtain a 24-hour measurement with one sleep phase from each measurement week and subject. A week was defined as the sum of all measurements within a period of seven days. This primary segment would serve as the first-line comparison point of each measurement week, while the other segments, if there was enough time left, would serve as a secondary comparison in case the first one proved to be unusable after the upload. The default was to use the first 24 hours of the first measurement of the respective date. If that was not possible due to the measurement length or the sleep phase distribution, the last 24 hours of the measurement were used. If this option was also unavailable because of sleep phase distribution or due to faulty or empty recordings, the length of the segment could be adjusted to a period range of 18-30 hours to accommodate for these discrepancies and still ensure high comparability. The other parts of the measurements would be portioned off into separate segments, provided their length also fell within the range of 18-30 hours.

If there were multiple sleep phases within a single measurement (defined as more than one during a 24-hour period or more than two during a period of 50 hours), the methodology dictated several courses of action depending on their length and placement within the measurement segment. The main sleep phase (MSP) was defined as the longest sleep phase in the segment, all other sleep phases were categorized as additional sleep phases (ASP).

If an ASP was at the beginning or end of the measurement, it would have to be cut out of the segment, on the condition that the rest of the segment was long enough to fit within the time range of 18-30 hours.

If the wake phase between the MSP and one or more ASPs was as short as one hour in total, the MSP and ASP(s) would be combined into a single sleep phase which would then become the new MSP, with a note that there is an included wake phase within.

If all ASPs had a total duration of up to two hours, they would be included into the wake phase, the segments of which would also be noted as having sleep time within their wake phase.

Measurements that could not meet these prerequisites were excluded from the final analysis. In case I encountered any uncertainties, I consulted again with Mag. Grote.

Table 5: proposed segment cutting

Nr.	NOM	date	dur.	1st WP	1st SP	2nd WP	Nr.	NOM	date	dur.	1st WP	1st SP	2nd WP
802							**809**						
1a	M1_1	26.04.2012	24	10:27-18:30	18:30-02:54	02:54-10:27	27a	M1_1	16.04.2012	24	10:34-19:37	19:37-03:18	03:18-10:34
1b	M1_2	27.04.2012	22	10:27-15:00	15:00-03:01	03:01-08:13	28a	M2_1	14.06.2012	24	15:53-18:03	18:03-03:43	03:43-18:48
2a	M2_1	12.06.2012	24	08:04-15:03	15:03-03:16	03:16-08:04	28b	M2_2	15.06.2012	26	03:43-18:48	18:48-03:51	03:51-17:53
2b	M2_2	13.06.2012	26	08:04-19:18	19:18-03:02	03:02-10:04	29a	M3_1	25.07.2012	25	18:10-02:38	02:38-05:04	05:04-18:39
3a	M3_1	29.07.2012	24	12:54-15:05	15:05-03:53	03:53-12:54	29b	M3_2	26.07.2012	24	18:39-23:20	23:20-05:47	05:47-18:39
3b	M3_2	30.07.2012	26	12:54-15:10	15:10-03:31	03:31-14:55	30a	M3_3	27.07.2012	24	20:58-22:21	22:21-09:41	09:41-20:58
4a	M4_1	08.09.2012	21	11:35-16:00	16:00-06:04	06:04-08:30	31a	M4_1	05.09.2012	24	12:07-20:52	20:52-05:54	05:54-12:07
4b	M4_2	09.09.2012	24	13:35-15:00	15:00-03:33	03:33-13:35	31b	M4_2	06.09.2012	24	12:07-18:08	18:08-05:55	05:55-12:08
803							32a	M5_1	11.10.2012	24	19:01-22:01	22:01-07:43	07:43-19:01
5a	M1_1	01.05.2012	24	11:07-18:00	18:00-04:40	04:40-11:07	32b	M5_2	12.10.2012	23	19:01-20:34	20:34-07:37	07:37-17:50
6a	M1_2	02.05.2012	22	X	17:43-05:08	05:08-15:05	**810**						
7a	M2_1	09.06.2012	24	19:14-20:44	20:44-05:56	05:56-19:14	33a	M1_1	19.04.2012	24	11:47-22:55	22:55-02:09	02:09-11:47
7b	M2_2	10.06.2012	26	19:14-20:39	20:39-04:58	04:58-21:14	33b	M1_2	20.04.2012	26	11:47-15:32	15:32-03:08	03:08-13:51
8a	M3_1	23.07.2012	24	10:52-19:55	19:55-04:35	04:35-10:52	34a	M2_1	07.06.2012	24	11:43-15:27	15:27-23:19	23:19-11:43
8b	M3_2	24.07.2012	26	10:52-18:00	18:00-04:55	04:55-12:52	34b	M2_2	08.06.2012	26	11:43-23:31	23:31-05:56	05:06-13:43
9a	M4_1	01.09.2012	26	04:44-20:43	20:43-05:00	05:00-06:40	35a	M3_1	20.08.2012	24	06:00-15:22	15:22-20:08	20:08-06:00
9b	M4_2	02.09.2012	24	06:40-19:20	19:20-04:40	04:40-06:40	36a	M4_1	21.10.2012	24	06:04-19:45	19:45-02:20	02:20-06:04
10a	M5_1	03.10.2012	24	15:32-18:10	18:10-03:50	03:50-15:32	36b	M4_2	22.10.2012	26	06:04-19:03	19:03-02:12	02:12-08:04
10b	M5_2	04.10.2012	26	15:32-20:54	20:54-06:04	06:04-17:33	**806**						
804							37a	M1_1	21.03.2012	24	11:36-22:40	22:40-06:06	06:06-11:36
11a	M1_1	15.03.2012	24	10:00-18:57	18:57-06:00	06:00-10:00	39a	M2_1	05.07.2012	24	18:05-20:18	20:18-04:32	04:32-18:05
12a	M2_1	07.05.2012	19	09:28-21:47	21:47-04:23	X	39b	M2_2	06.07.2012	26	18:05-20:15	20:15-06:00	06:00-20:06
13a	M3_1	13.07.2012	24	11:31-20:39	20:39-07:00	07:00-11:31	41a	M3_1	09.08.2012	20	19:58-20:06	20:06-01:13	01:13-16:00
13b	M3_2	14.07.2012	26	X	X	X	41b	M3_2	10.08.2012	24	16:00-20:38	20:38-04:06	04:06-16:00
14a	M3_3	16.07.2012	24	18:12-20:40	20:40-03:10	03:10-18:12	43a	M4_1	18.09.2012	24	14:27-19:40	19:40-02:00	02:00-14:27
14b	M3_4	17.07.2012	26	18:12-22:30	22:30-04:56	04:56-20:12	43b	M4_2	19.09.2012	26	14:27-20:28	20:28-03:59	03:59-16:27
15a	M4_1	16.08.2012	24	09:52-09:59	09:59-18:30	18:30-09:52	**807**						
15b	M4_2	17.08.2012	26	09:52-12:57	12:57 -21:24	21:24-11:52	44a	M1_1	13.04.2012	24	10:03-18:30	18:30-02:58	02:58-10:03
16a	M5_1	09.10.2012	24	10:26-22:58	22:58-07:22	07:22-10:26	45a	M2_1	11.05.2012	24	18:49-19:41	19:41-05:23	05:23-18:49
805							45b	M2_2	12.05.2012	26	18:49-22:40	22:40-05:32	05:32-20:50
17a	M1_1	02.05.2012	24	05:57-19:00	19:00-04:01	04:01-05:57	46a	M3_1	08.07.2012	24	15:21-18:56	18:56-00:56	00:56-15:03
18a	M2_1	31.07.2012	24	16:08-18:08	18:08-05:15	05:15-16:08	46b	M3_2	09.07.2012	24	15:03-15:11	15:11-01:10	01:10-15:03
18b	M2_2	01.08.2012	22	16:08-20:00	20:00-05:28	05:28-14:34	47a	M4_1	07.08.2012	22	09:34-18:49	18:49-02:02	02:02-07:44
19a	M3_1	11.09.2012	24	06:06-19:09	19:09-03:20	03:20-06:06	47b	M4_2	08.08.2012	28	X	07:44-12:11	12:11-11:35
19b	M3_2	12.09.2012	26	06:06-18:30	18:30-04:28	04:28-08:06	**808**						
801							48a	M1_1	11.04.2012	24	07:51-19:03	19:03-01:45	01:45-07:51
22a	M1_1	08.03.2012	24	09:12-22:00	22:00-04:24	04:24-09:12	49a	M2_1	17.05.2012	24	07:38-17:55	17:55-01:25	01:25-07:38
23a	M2_1	21.05.2012	24	09:25-20:38	20:38-04:01	04:01-09:25	49b	M2_2	18.05.2012	24	07:38-19:13	19:13-03:00	03:00-07:30
23b	M2_2	22.05.2012	26	09:25-21:41	21:41-05:45	05:45-11:26	50a	M3_1	22.08.2012	24	10:01-18:31	18:31-02:24	02:24-10:01
24a	M3_1	26.06.2012	24	13:37-20:40	20:40-03:44	03:44-17:45	51a	M4_1	29.09.2012	24	10:42-17:30	17:30-02:45	02:45-10:42
24b	M3_2	27.06.2012	26	03:44-17:45	17:45-03:44	03:44-15:37	51b	M4_2	30.09.2012	26	10:42-17:58	17:58-02:00	02:00-12:42
25a	M4_1	02.08.2012	24	16:09-00:20	00:20-08:52	08:52-16:09							
25b	M4_2	03.08.2012	25	16:09-21:45	21:45-04:05	04:05-16:49							
26a	M5_1	13.09.2012	24	14:21-21:30	21:30-03:18	03:18-14:21							
26b	M5_2	14.09.2012	26	14:21-23:52	23:52-06:00	06:00-15:49							

3.4 Uploading the data

Once the standardization was complete, the upload could begin. For this purpose I got an ID and password from the IT department with which I could log in on the website www.apps.humanresearch.at. Once I logged in I had to create a list of all subjects involved in the study with anonymized IDs including the date of birth and sex. For each segment, a separate date had to be created within the program, even though some measurement segments had data from

two consecutive days. Every segment within a period of seven days was designated with the same letter (M) and number. So for example, the segment dates M1_1 and M1_2 would originate from the same measurement week, possibly even the same measurement, whereas M1_1 and M2_1 were measured at different points in time.

Once the date was established I could upload the data online by manually entering the information on the measurements (start time, date, and sleep time). Of the three data formats received from each measurement, only the fif file is uploaded, ideally with the activity protocol, which was unavailable in this case.

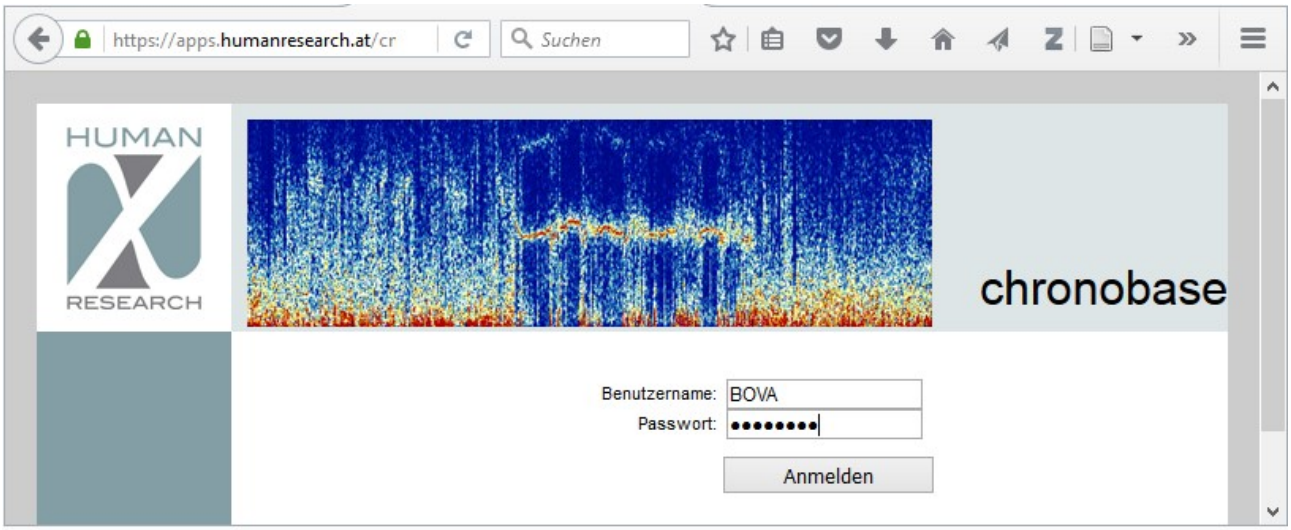


Figure 15: Step 1: HRI Login; © Human Research Institut, Weiz, www.humanresearch.at

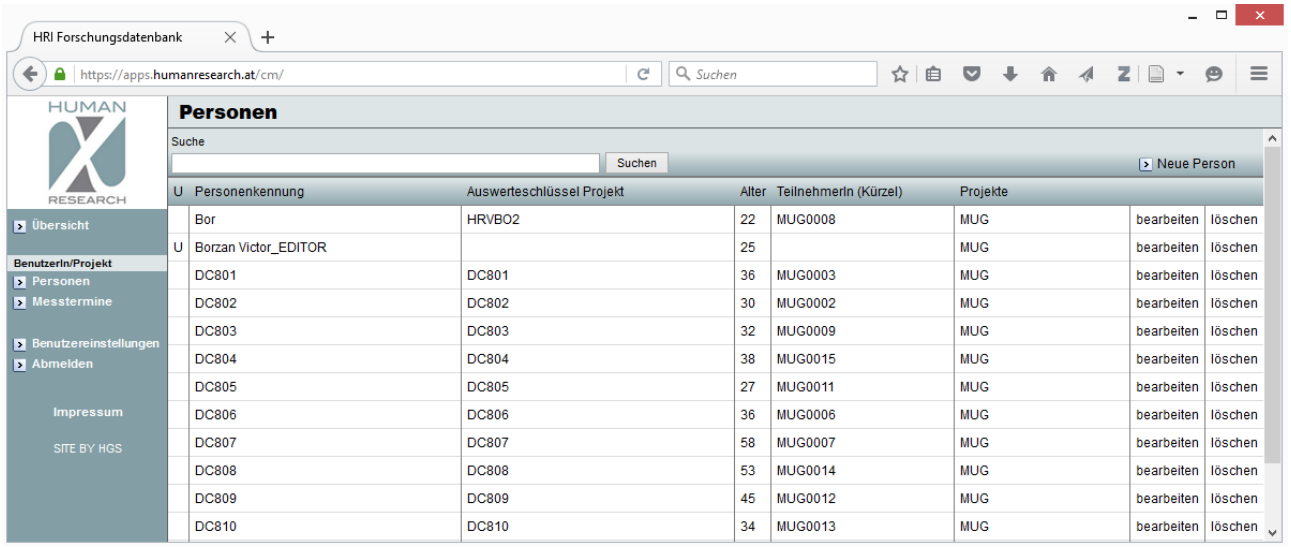


Figure 16: Step 2: Create a Subject List; © Human Research Institut, Weiz, www.humanresearch.at

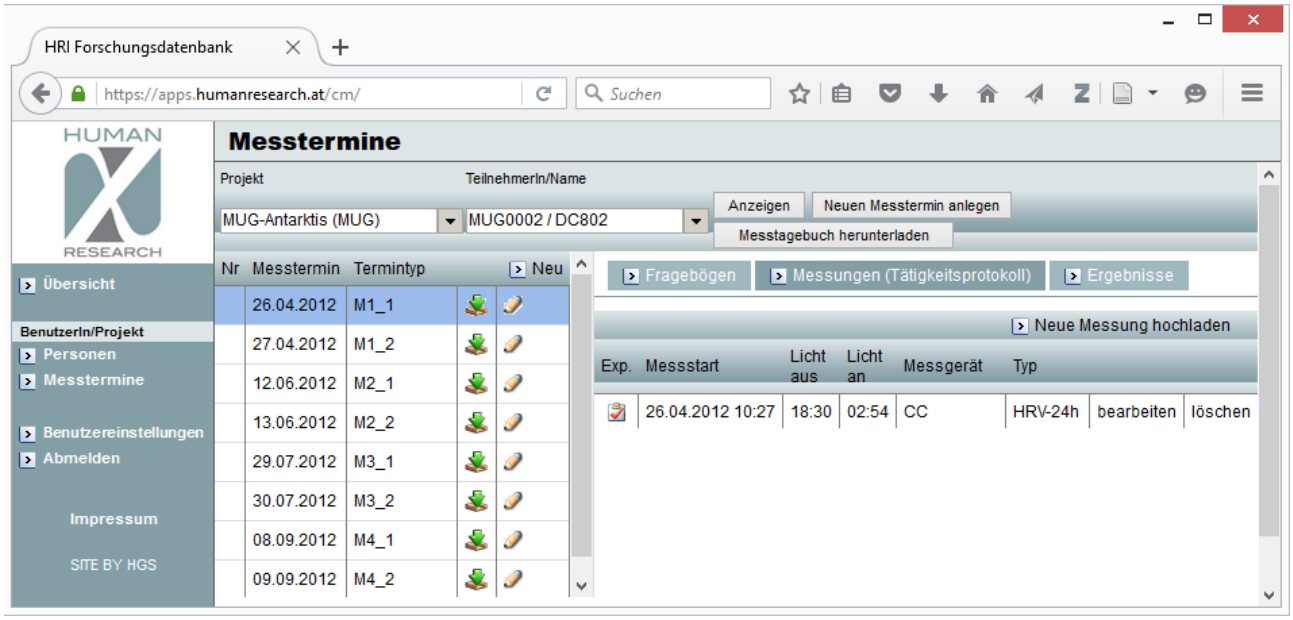


Figure 17: Step 3: Create a Date for each Measurement Segment; © Human Research Institut, Weiz, www.humanresearch.at

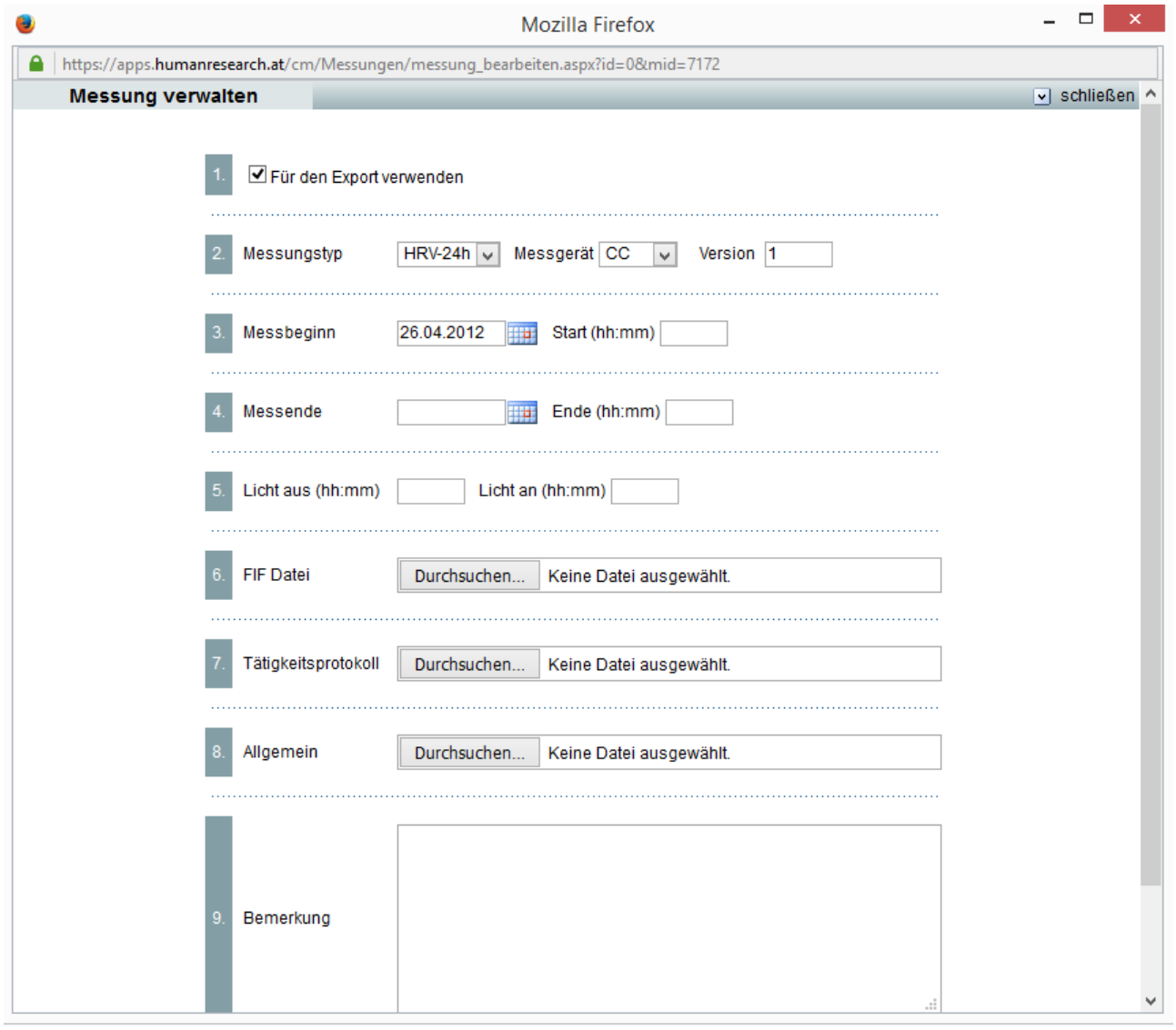


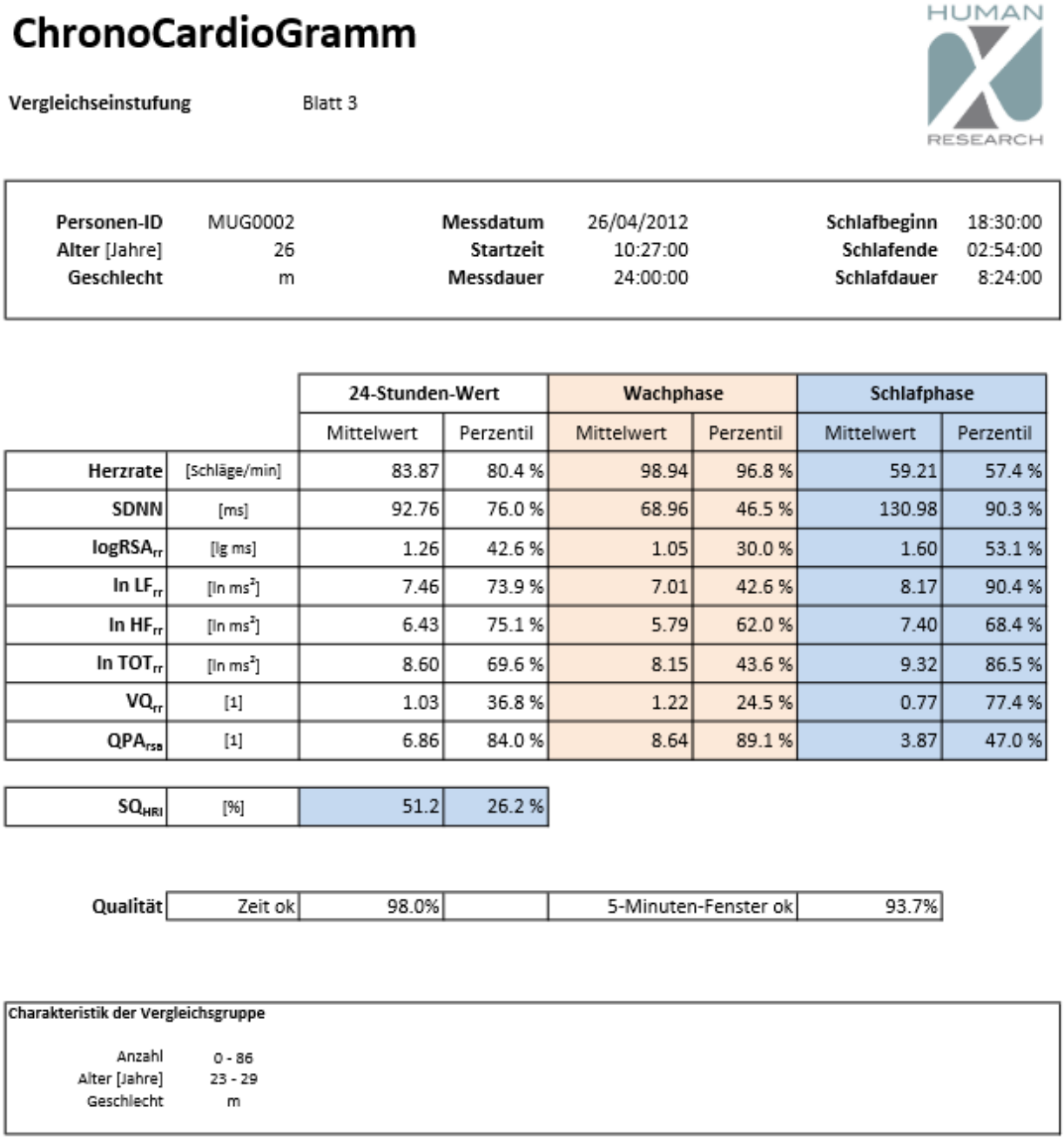
Figure 18: Step 4: Upload the fif-file with the additional Information (Start Time, Sleep Period); © Human Research Institut, Weiz, www.humanresearch.at

The program needs only a few minutes to convert the file into usable HRV parameters. The results are shown in three different pdf-files.

The first pdf-file contains a table listing the time and frequency domain parameters. Apart from the SDNN value, the program also calculates the common logarithm of the respiratory sinus arrhythmia ($logRSA_{rr}$), the natural logarithm of the LF band (ln LF_{rr}), HF band (ln HF_{rr}) and total variability, which represents the sum of both LF and HF bands (ln TOT_{rr}), the vegetative quotient (VQ_{rr}), which is equal to ln LF divided by ln HF, the pulse respiratory quotient (QPA_{rsa}) and the sleep quality (SQ_{HRI}). The last parameter is a value calculated by the HRI and a unique feature among HRV measurements. However, for this diploma thesis, it was not used as a variable for analysis, as I lack the means to explain its origin and how it is computed.

In this file, the unit for SDNN, milliseconds, was abbreviated as [ms], as was the case with the variable logRSA, its unit being logarithmized (to the base of ten) milliseconds. Ln LF, ln HF and ln TOT on the other hand had the units logarithmized (to the base e) milliseconds squared, thus being abbreviated [ln ms^2]. His QPA will only be analyzed during his sleep hours fpr the purposes of this thesis, as it is influenced by several other causes than HRV during the wake hours, such as emotion and physical activity.

All values are calculated in three separate columns, one for the 24-hour mean values, one for the wake phase values and one for the sleep time values. In each columns there are the absolute values on the left and the percentiles compared with other measurements in the HRI database from people in the same age group (age of the subject in years ± 3 years). On each of the three pdf-files there is an indicator for the quality of the measurement.



ChronoCardioGramm

Vergleichseinstufung Blatt 3

HUMAN RESEARCH

Personen-ID	MUG0002	**Messdatum**	26/04/2012	**Schlafbeginn**	18:30:00
Alter [Jahre]	26	**Startzeit**	10:27:00	**Schlafende**	02:54:00
Geschlecht	m	**Messdauer**	24:00:00	**Schlafdauer**	8:24:00

		24-Stunden-Wert		Wachphase		Schlafphase	
		Mittelwert	Perzentil	Mittelwert	Perzentil	Mittelwert	Perzentil
Herzrate	[Schläge/min]	83.87	80.4 %	98.94	96.8 %	59.21	57.4 %
SDNN	[ms]	92.76	76.0 %	68.96	46.5 %	130.98	90.3 %
logRSA$_{rr}$	[lg ms]	1.26	42.6 %	1.05	30.0 %	1.60	53.1 %
ln LF$_{rr}$	[ln ms^2]	7.46	73.9 %	7.01	42.6 %	8.17	90.4 %
ln HF$_{rr}$	[ln ms^2]	6.43	75.1 %	5.79	62.0 %	7.40	68.4 %
ln TOT$_{rr}$	[ln ms^2]	8.60	69.6 %	8.15	43.6 %	9.32	86.5 %
VQ$_{rr}$	[1]	1.03	36.8 %	1.22	24.5 %	0.77	77.4 %
QPA$_{rsa}$	[1]	6.86	84.0 %	8.64	89.1 %	3.87	47.0 %

SQ$_{HRI}$	[%]	51.2	26.2 %

Qualität	Zeit ok	98.0%		5-Minuten-Fenster ok	93.7%

Charakteristik der Vergleichsgruppe

Anzahl	0 - 86
Alter [Jahre]	23 - 29
Geschlecht	m

Figure 19: First pdf-file containing HRV Parameters; © Human Research Institut, Weiz, www.humanresearch.at

The second pdf-file is a compilation of visualizations of the parameters from the first pdf-file. At the top there is a separation of the HRV into the composing frequencies from the LF/HF bands. The activity of the frequencies is color-coded, with red indicating a high influence of this frequency on HRV at that time, while blue means no activity at that particular frequency at the time. Right below is the diagram showing the progress of ln LF_{rr}, ln HF_{rr} and ln TOT_{rr} over time, followed by a display of autonomic balance over time. In this figure, red means that the subject is experiencing strain, while blue indicates rest and relaxation. Next comes a visualization of the SDNN and log RSA_{rr} values over time, right above the depiction of the heart rate and pulse respiratory quotient over

time. The QPA_{rsa} is a particularly useful parameter when it comes to determining sleep phases, as it settles to a proportion of 4 heart beats per breath during sleep, thus distinguishing sleep and wake phases (60). On the bottom of the page is the activity protocol, which in our case was only separated into awake and asleep. On the right of each graph is the average value of the respective parameter as determined by the program.

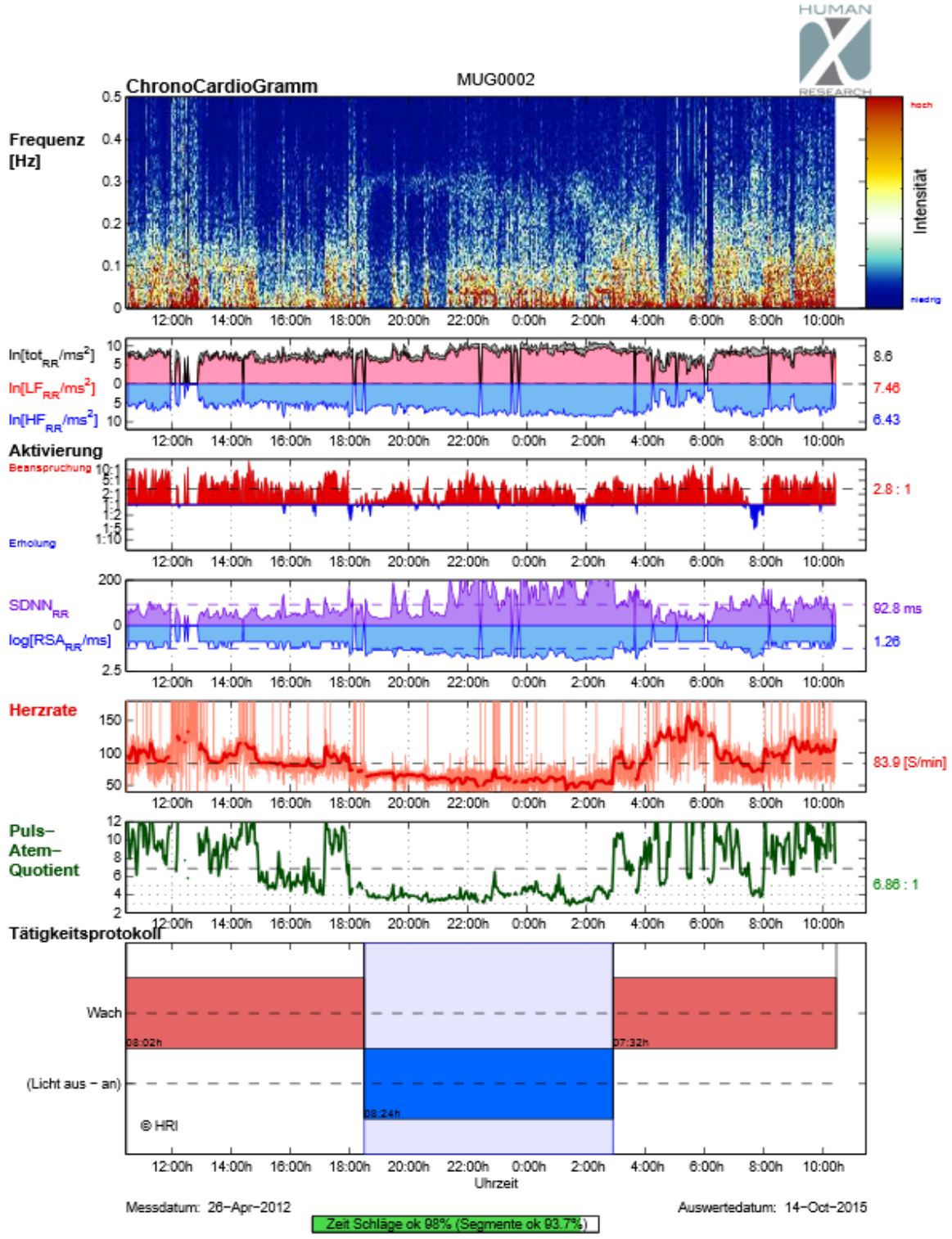


Figure 20: Second pdf-file containing the Graphs of the Parameters in the first pdf-file; © Human Research Institut, Weiz, www.humanresearch.at

The third pdf-file shows the heart rate, respiratory sinus arrhythmia and the activation of the ANS compared with the mean values of the age group (shown as highlights in the background), along with a chart beneath each graph indicating the influence of the SNS and PNS leading to those values. At the bottom of the page there is another copy of the activity protocol to cross-reference the values with the respective activity at the time.

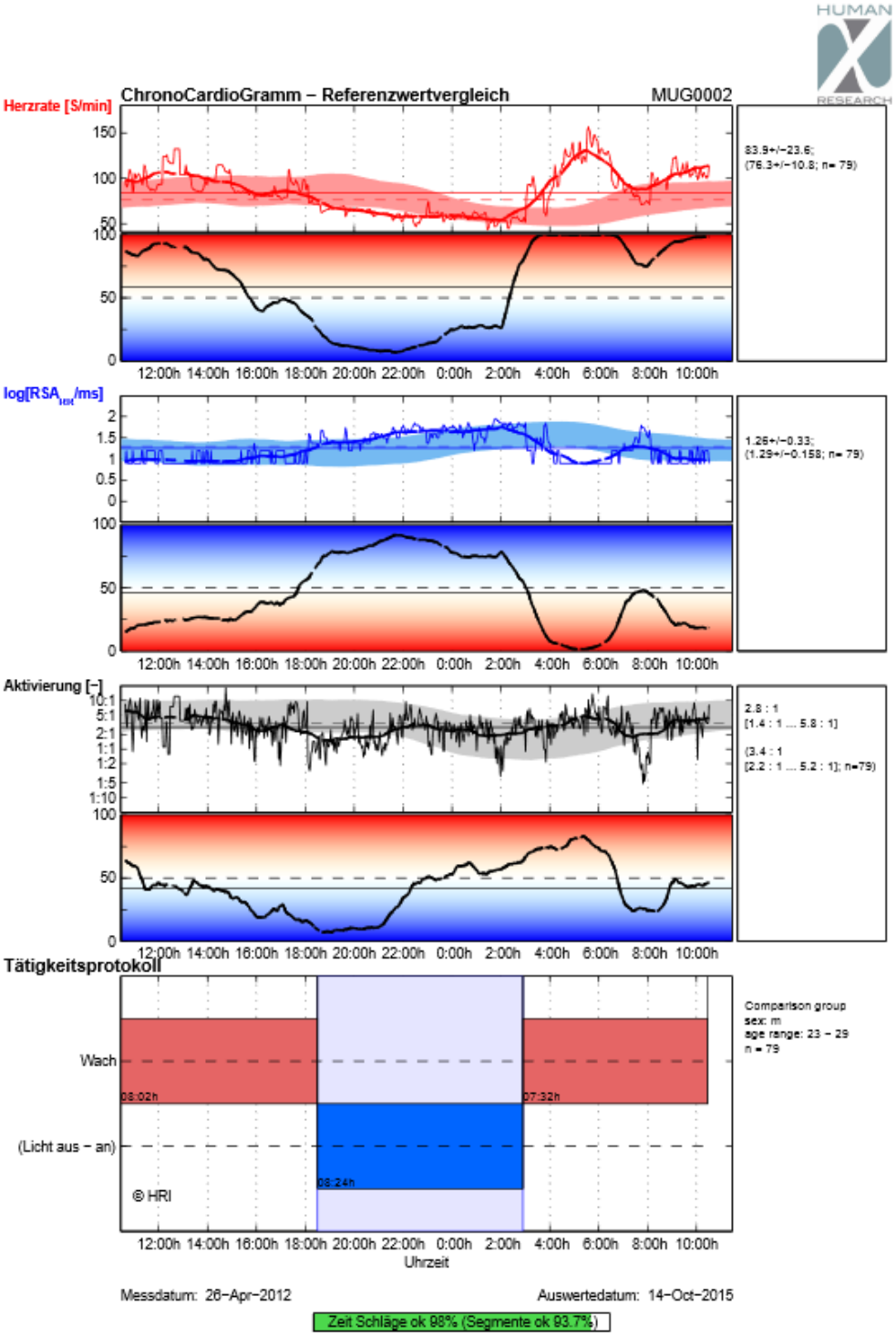


Figure 21: Third pdf-file with the References from the same Age Group as the Subject; © Human Research Institut, Weiz, www.humanresearch.at

3.5 Second validation

Once the upload was fully completed, there was a second round of evaluation to check if the sleep phases were entered correctly. The pdf-files contain visual representations of both wake and sleep phases, with some parameters having distinct differences between the two. The second pdf-file had three graphs in particular which were very important in this regard, namely the frequency analysis, the heart rate and the QPA. While the heart rate and QPA have already been established as important markers for differentiating wake from sleep (see above), the frequency band also plays a role.

The next step of evaluation was determining whether the data from any single measurement was admissible as a whole. For the purpose of answering this question, I took another look at the quality information of the measurement as determined by the HRI program. It specified two values in percent, one being the overall percentage of usable data, the other a percentage of valid 5-minute periods of the measurement. Both are important for determining whether the measurement was even reliable and if the data obtained from that session should be used for analysis. This information however was only relevant for the investigator, not for the program itself. It did not have a demarcation line to evaluate the measurements, if it had enough values it calculated the HRV parameters regardless of the quality statement. The opposite could also occur. Therefore, I defined the quality percentage as explained below, beneath which the measurement would not be admissible.

In case the recording was faulty during a transition of sleep to wake or wake to sleep and therefore, the transition point became unreadable in the pdf with a confidence margin of ± 30 minutes, the measurement would not be admissible. If during observation the investigator would discover that either the wake phase or sleep phase was largely invalid due to faulty data, the measurement would also be excluded from analysis. This clause was however not exactly defined, as the program did not give a quality assessment on a single wake or sleep phase, but on the measurement as a whole. Therefore, exclusion based on this factor would have to be discussed and agreed upon with a senior member of the HRI.

However, an exact exclusion point was a combined quality reading of having less than 80 percent valid data from the measurement and less than 70 percent of the 5-minute segments. The 5-minute segment limit was set lower than the overall percentage due to the fact that only a few seconds of faulty data was required to render the whole 5-minute segment at least partially faulty. If both those quality readings were below their respective threshold, the measurement would be

excluded from analysis. If both or only one of the two quality parameters were above their limit, the measurement would be included. This is explainable by the fact that if only the overall quality is below 80 percent, but more than 70 percent of the segments are valid, it means that the invalid data is mostly localized to a few segments, meaning that most of the measurement is clean. Likewise, if less than 70 percent of the segments are valid with more than 80 percent of the overall information being admissible, it means that a few single invalid measurements are distributed among many segments, also meaning that most of the measurement is admissible.

To ensure the overall quality of the measurement, if the overall percentage of admissible data was below 70 percent, the measurement was excluded from analysis, independent of the 5-minute segment quality.

3.6 Final processing and analysis

As the sample number was by not representative of the general population, in this study the subjects were not compared with each other. Instead they were evaluated individually in the form of case reports. This approach had the advantage that each test person provided their own comparison over time, while at the same time compensating for any missing baseline measurements and thereby circumventing the physiological differences the subjects had had prior to the beginning of the stay at Concordia base.

For this diploma thesis, only the first and the second pdf-files from each upload were needed. At first the data from the first pdf-file was selected based on the methodology described above and entered into SPSS version 23. By looking at the values calculated by the HRI-software, any trends and changes located visually in the second pdf-file could be confirmed or disproved. The changes over time were also shown by means of various diagrams. Note that in those diagrams, the wake values of the respective variable were also shown, however they were mostly disregarded for the purposes of this thesis, as the activity protocols were left blank and therefore the values could not be interpreted. The percentiles of each value were included in brackets behind the corresponding value.

Additionally the second pdf-file of every measurement was matched with others visually by comparing the CCGs. I looked specifically for signs of sleep disruption, the difference of REM and non-REM sleep stages and periodic breathing, a sign of hypoxia (61). This approach was used to look at the changes during the same sleep or wake phase, as well as the changes the stay in Antarctica induced on the individuals.

There were several reasons why the study was analyzed purely with descriptive statistical means instead of analyzing statistics. In order to perform tests which would show the statistical significance of the results, there were several prerequisites that could not be met. The first step would be finding out if the data was normally distributed. However, the only way to get sufficient points of data would have been to combine the data of all subjects for each variable. That in turn would have created misleading results, as the test subjects had very different starting variables from before their stay. The only way to adjust for this discrepancy would have been to take at least one measurement before the beginning of the journey to Antarctica simultaneously from each subject, and compare their starting values. However, while this course of action was suggested in the proposal for this study, it was not carried out due to the logistics of their arrivals (They arrived separately from different countries at different points in time). This circumstance also presented a problem when comparing the data. Even without any pre-Antarctic measurements it still would have been possible to compare the measurements from the subjects with their first measurements representing the common baseline and to look at the change in their mean values. However, that would have required that every participant takes the measurements simultaneously, and at the same intervals no less. That was impossible however due to the presence of only two measuring devices, which meant doing measurements in shifts was the only option available.

4 Results

4.1 Selection of valid segments

Of the proposed segments, seven segments were inadmissible due to the quality of the measurement, three more were disqualified because the wake and sleep phase borders could not be assessed by a reasonable margin (see above), and two were excluded as a result of too long ASPs. The segments in question are listed in table 6. All the other measurements were analyzed using SPSS version 23. Of all test subjects, 804 had the most unreliable measurements, with over half of his measurements being disregarded due to their overall quality.

Table 6: Inadmissible Measurement Segments

ID	NOM	Quality [%]	5-Minute Quality [%]	Reason for Dismissal
801	M1_1	99,7	99,2	ASP-duration > 2 hours
804	M1_1	26,6	8,1	Overall Quality
804	M3_1	73,2	61,6	Overall Quality
804	M3_2	11,8	1,5	Overall Quality
804	M3_4	57,0	50,3	Overall Quality
804	M4_2	80,5	52,8	Overall Quality
805	M1_1	88,9	65,5	Wake Phase Quality
806	M3_1	75,8	72,5	Sleep Phase Quality
807	M4_2	98,2	89,2	ASP-duration > 2 hours
808	M2_2	76,2	60,4	Overall Quality
808	M4_1	92,5	85,5	Sleep Phase Quality
810	M4_1	76,5	69,0	Overall Quality

4.2 Individual Results

4.2.1 Subject 801

Table 7: 801´s Measurement Segments

Number	Date	Number	Date
M2_1	21.05.12	M4_1	02.08.12
M2_2	22.05.12	M4_2	03.08.12
M3_1	26.06.12	M5_1	13.09.12
M3_2	27.06.12	M5_2	14.09.12

The first subject did five measurements, which were cut into 9 segments. The first segment was declared invalid due to an ASP which exceeded our threshold length, resulting in 8 segments

(see Table 7 above). Consequently, his first segment dates back to May 21st, giving us no information on the start of his stay and how and if his HRV shifted at the beginning. However, for the rest of the period in Concordia, we had reliable data on how he adapted to the environment.

Shown below is a typical CCG tracing of this subject and the sleep patterns taken over 24 hours.

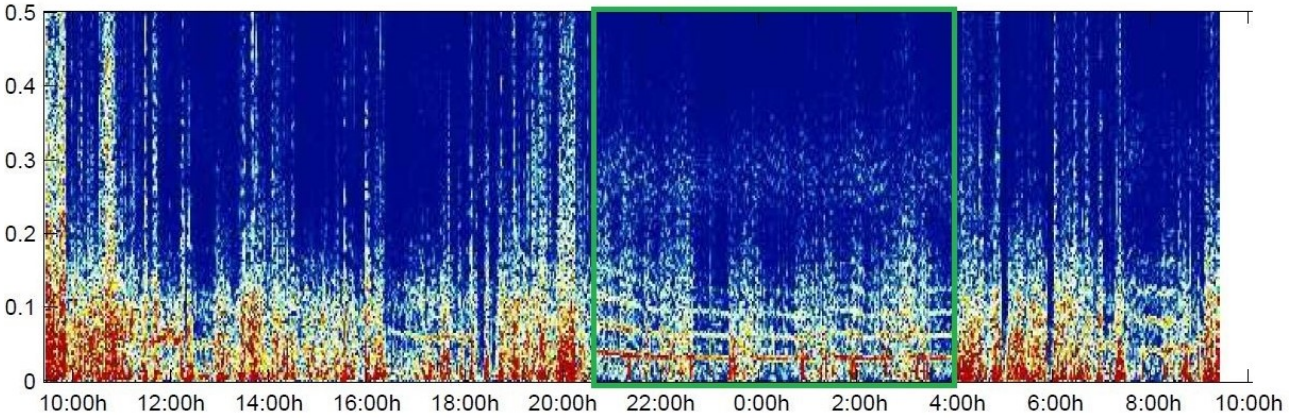


Figure 22: A typical CCG from this Subject; The MSP is marked by a green rectangle, within which there are specific frequency bands during non-REM sleep associated with hypoxia; Almost at the end there is an ASP recognizable through periodic breathing.

In regards to his sleep, the sleep durations during M5_1 and M5_2 were much shorter than those of previous measurements. While M2_1 through M4_2 had sleep times (MSP+ASP) ranging from 7,38 hours to 9,98 hours, M5_1 and M5_2 dropped to 5,80 and 6,13 hours of sleep respectively, a decrease of 30 and 27 percent compared with the prior average of 8,30 hours.

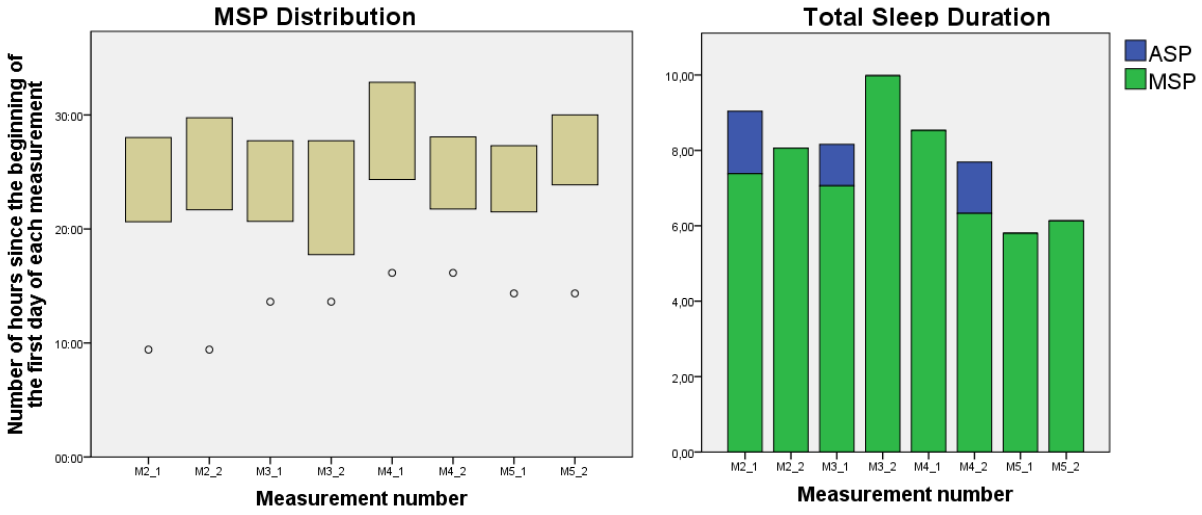


Figure 23: Sleep Distribution and Duration; the bars on the left show the start and end of each MSP, along with the start of the respective measurement (marked by dots). For example, in M2_1 the subject went to sleep shortly after 8 pm of the first measurement day and woke up at 4 am the next day; the bars on the right show the sum of MSP and ASP of each measurement.

The heart rate, starting at a mean value of 79,46 bpm (73rd p.) over 24 hours, fluctuated only between 77,64 bpm (64th p.) and 83,05 bpm (81st p.) during the first 5 measurements, then rose to 90,09 (93rd p.), 87,60 (89th p.) and 91,01 bpm (96th p.) in the last three measurements M4_2, M5_1

and M5_2 respectively.

His mean sleep heart rate changed from a range of 54,55 (26th p.) to 56,74 bpm (42nd p.) during his first five measurements to a range of 59,99 (55th p.) to 81,45 bpm (99th p.) in his last three segments M4_2 to M5_2.

The mean 24-hour standard deviation of the intervals between the R-spikes of the QRS complex in M2_1 was 80,76 ms (68th p.). Including his next four segments, his SDNN was lowest at 79,92 ms (68th p.) in M2_2 and highest in M3_1 at 83,85 ms (73rd p.). In his last three segments, it decreased to 72,30 ms (50th p.), 68,33 ms (40th p.) and 62,98 ms (26th p.) consecutively.

His sleep SDNN sank continually since his first segment, where it was 112,50 ms (88th p.), to 57,62 ms (9th p.) in M5_2. The only exception is M4_1, where it increased from the previous 93,44 ms (71st p.) to 103,93 ms (81st. p., however the next segment M4_2 furthered the decline by dropping to 90,69 ms (67th p.).

His highest value in regards to respiratory sinus arrhythmia was M3_1, where he reached the mean 24-hour value of 1,19 log ms (42nd p.), a mean wake value of 1,09 log ms (41st. p.), and a mean sleep value of 1,41 log ms (43rd p.). However, as was the case with the other two variables, his 24-hour mean values and his sleep mean values decreased concurrently in the last three measurements below the previous minimal values in both categories.

Ln LF also correlated with the previous variables, with M1_1 having a mean 24-hour value of 7,33 ln ms² (69th p.) and subsequently sinking to 7,03 ln ms² (46th p.) in M3_2. In M4_1 it returned to 7,32 ln ms² (68th p.), before dropping to 6,98 (43rd p.), 6,94 (38th p.) and 6,81 ln ms² (33rd p.) in the last three consecutive segments respectively. His sleep values started at 8,07 ln ms² (97th p.) and showed the same downward trend, however in addition to M4_1´s 7,69 ln ms² (81st p.), the segment M5_1 also had a higher value, 7,21 ln ms² (56th p.), than the previous segment M4_2, which had a value of 7,12 ln ms² (50th p.) and therefore those two segments contradicted the decreasing course of the other segments.

Four of the first five measurement segments of ln HF were almost identical in their mean 24-hour values, with the highest being 5,70 ln ms² (51st p.) in M3_2 and the lowest 5,59 ln ms² (47th p.) in M4_1. Only M2_2 fell beneath that minimum with a value of 5,29 ln ms² (36th p.). The last three segments were again below the latest number, with values of 5,11 (22nd p.), 4,91 (17th p.) and 4,62 ln ms² (9th p.). His sleep values showed the same trend, M2_2 had an extreme low value in the first five measurement segments with a value of 6,19 ln ms² (46th p.), while the other values dropped consistently from 6,80 (64th p.) to 3,98 ln ms² (1st p.), with the two most marked declines between M4_1 and M4_2 from 6,47 (51st p.) to 5,70 ln ms² (29th p.) as well as M5_1 and M5_2 from 5,61 (26th

p.) to 3,98 ln ms² (1st p.) respectively.

His mean 24-hour values started at 8,40 ln ms² (65th p.) in M2_1 and changed between 8,33 ln ms² (61st p.) in M3_2 and 8,47 ln ms² (68th p.) in M4_1, before again dropping in the last three measurements, first to 8,18 ln ms² (48th p.), then to 8,12 ln ms² (42nd p.) and finally to 7.96 ln ms² (26th p.).

The ln TOT wake mean values only fluctuated between 7,97 ln ms² (43rd p.) in M2_1 and M5_1 and 8,10 ln ms² (48th p.) in M2_2. The only extreme value outside of that interval was M3_1 with a value of 8,27 ln ms² (62nd p.). His sleep mean values on the other hand declined over time, starting at 9,16 ln ms² (92nd p.) in M2_1 and dropping continuously to 8,51 ln ms² (62nd p.) in M5_1, with only one value in defiance of that trend, M4_1´s 8,97 ln ms² (86th p.), before falling precipitously to 7,59 ln ms² (8th p.) in the final M5_2 segment.

His 24-hour VQ mean values started at 1,68 (75th p.) in M2_1 and rose to 2,00 (94th p.) in M2_2, then decreased to 1,43 (53rd p.) and 1,33 (41st p.) in M3_1 and M3_2 respectively. During the second half of measurements, his 24-hour mean value increased again to 1,73 (78th p.) and 1,87 (87th p.) in M4_1 and M4_2 respectively, before reaching all-time highs in M5_1 and M5_2, with values of 2,03 (95th p.) and 2,19 (97th p.).

The exact same trend was also present in his sleep mean values, which started at 1,26 (73rd p.) and 1,57 (91st. p.) in his first two segments, before declining to 0,69 (45th p.) and 0,59 (40th p.) in M3_1 and M3_2 respectively, then rising again to 1,22 (72nd p.) and 1,42 (83rd p.) and his next two segments and finally beyond the first two segments with values of 1,60 (91st. p.) and 2,16 (98th p.) in his last two measurement segments.

The final variable QPA was calculated by dividing the heart rate with the number of breaths per minute. In the case of subject 801 it remained very constant during most of his stay, fluctuating between 3,35 (21st. p.) in M3_2 and 4,06 (58th p.) in M4_2. However in M5_2 there was a sharp increase of his mean QPA during sleep, rising to 5,60 (96th p.).

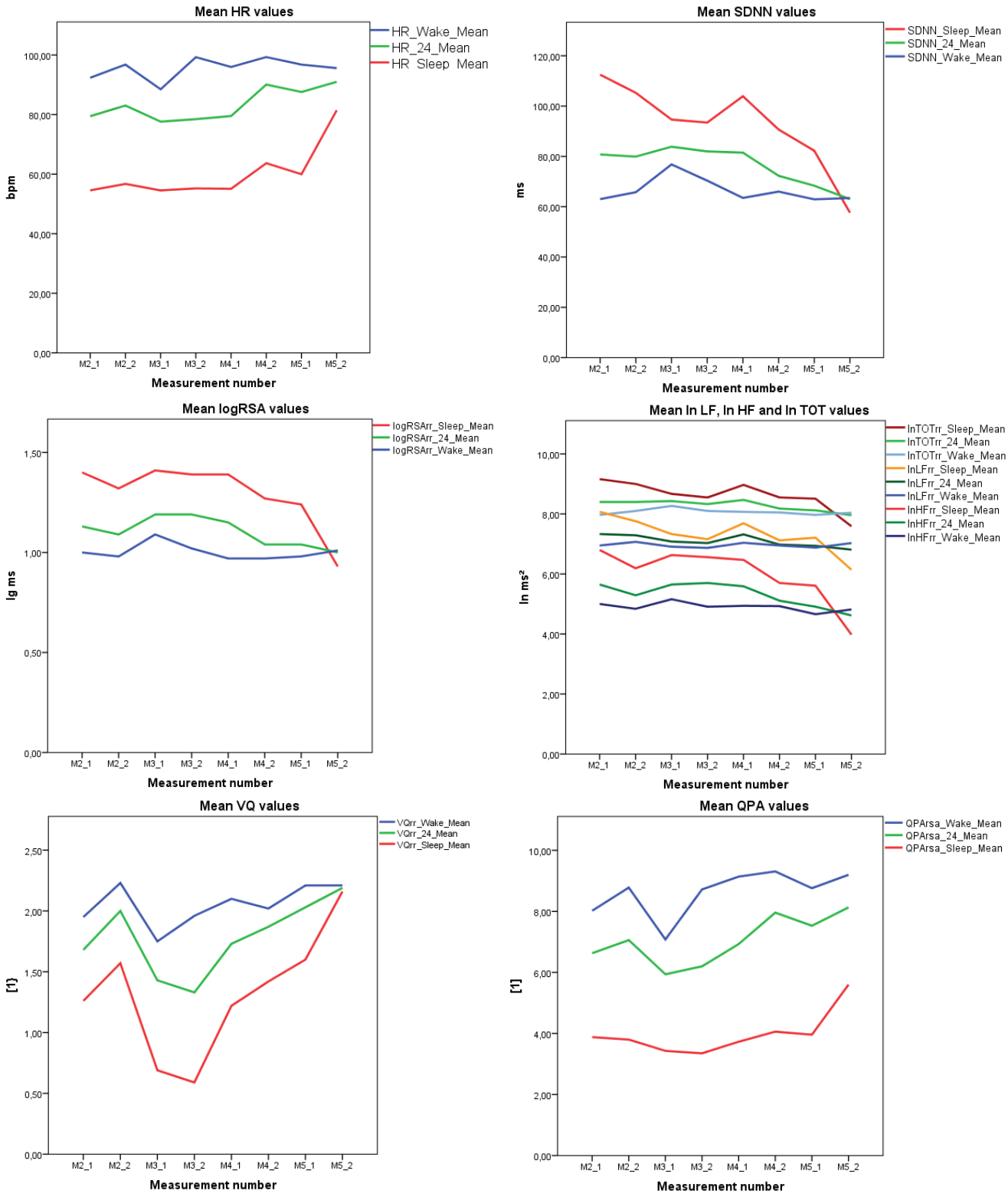


Figure 24: Diagrams of all Variables coded by Color: Sleep values are represented by shades of red, 24-hour mean values by green and wake values by blue. They show that the most dramatic change occurred in M5_2 across all variables but VQ

4.2.2 Subject 802

Table 8: 802´s Measurement Segments

Number	Date	Number	Date
M1_1	26.04.12	M3_1	29.07.12
M1_2	27.04.12	M3_2	30.07.12
M2_1	12.06.12	M4_1	08.09.12
M2_2	13.06.12	M4_2	09.09.12

Subject 802 had done four separate measurements during his stay at Concordia station, which were cut to eight different segments, all of which were declared valid as per the methodology of this thesis. Thus, his segments are numbered M1 to M4, with each measurement week containing two segments.

During his entire stay in Concordia, 802 slept at least twelve hours a day, M1_1 and M2_2 were the only two measurements with a shorter duration.

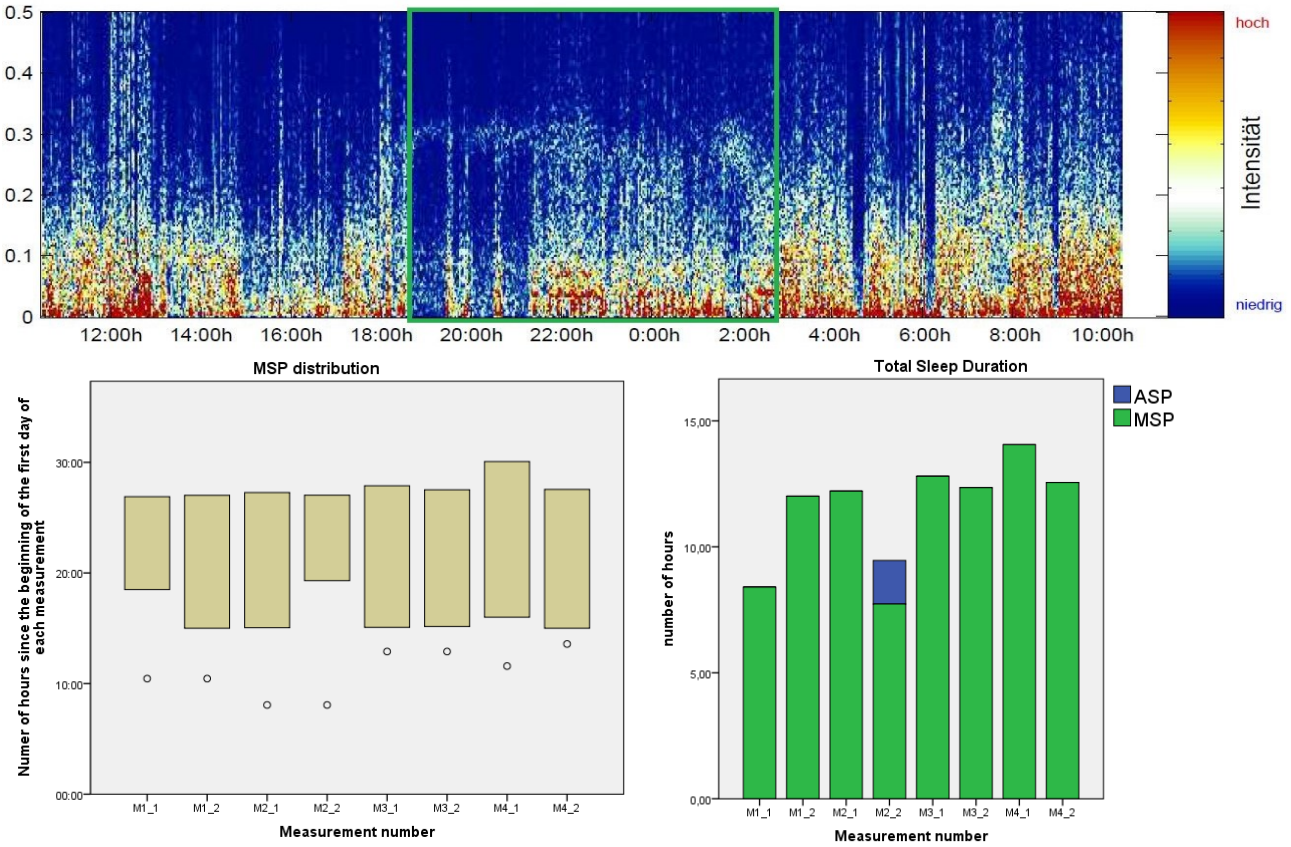


Figure 25: CCG, Sleep Distribution and Length; The CCG shows that in the middle of the MSP his sleep structure disappears, indicating some form of disruption; His sleep length and distribution are very similar to each other apart from M1_1 and M2_2

His 24-hour mean HR values were the highest at the beginning of his stay at 83,87 bpm (80th

p.) and 73,88 bpm (46th p.), then they decreased slightly to 70,96 bpm (38th p.) and 71,80 (39th p.) in M2_1 and M2_2 respectively, before sinking even further to 65,76 bpm (11th p.) and 67,89 bpm (23rd p.) in M3_1 and M3_2, as well as 65,74 bpm (11th p.) and 67,68 (20th p.) at the last two segments.

The lowest sleep mean value was in M3_1 at 53,27 bpm (29th p.) and the highest in M1_2 at 61,20 bpm (69th p.). The starting point had a value of 59,21 bpm (57th p.) and the last segment the value 58,00 bpm (52nd p.).

Similar results were discovered regarding his SDNN values, which were above average for his age group during his entire stay. His 24-hour mean values increased from an initial 92,76 ms (76th p.) to 121,82 ms (95th p.) in M4_2.

His sleep mean SDNN values were also above average, however they did not increase over time as was the case with the 24-hour values, but instead fluctuated during the months stationed there. He started at 130,98 (90th p.) and 115,45 ms (76th p.) in his first two segments, then dropped slightly to 104,85 (69th p.) and 124,53 ms (85th p.) before they climbed to 158,18 (99th p.) and 139,64 ms (94th p.) in M3_1 and M3_2 respectively and decreased again to 125,95 (85th p.) and 119,77 ms (82nd p.).

His 24-hour mean log RSA values started at 1,26 (43rd p.) and 1,45 lg ms (76th p.) in M1_1 and M1_2 respectively and increased to 1,55 (90th p.) and 1,58 lg ms (92nd p.) in his last two respective segments, while his sleep mean values rose slightly from his starting 1,60 (53rd p.) and 1,61 lg ms (55th p.) in the first two segments to 1,68 (66th p.) and 1,70 lg ms (70th p.) in M4_1 and M4_2 respectively.

His ln LF, ln HF and ln TOT values followed the trend of previous variables, as in all three cases his mean 24-hour values started at least above the 70th percentile in the first four segments, and continued to climb, resulting in values above the 90th percentile in the latter half of all the segments. His sleep values were still above the 60th percentile in his beginning four segments and improved to values above the 75th percentile.

His 24-hour VQ started at 1,03 (37th p.) in M1_1 and decreased to values below 1,00, his sleep mean value was 0,77 (77th p.) and decreased to only average levels, the lowest being 0,40 (43rd p.) in M2_2.

His QPA sleep mean values were constantly between 3,44 and 3,98 beats per breath.

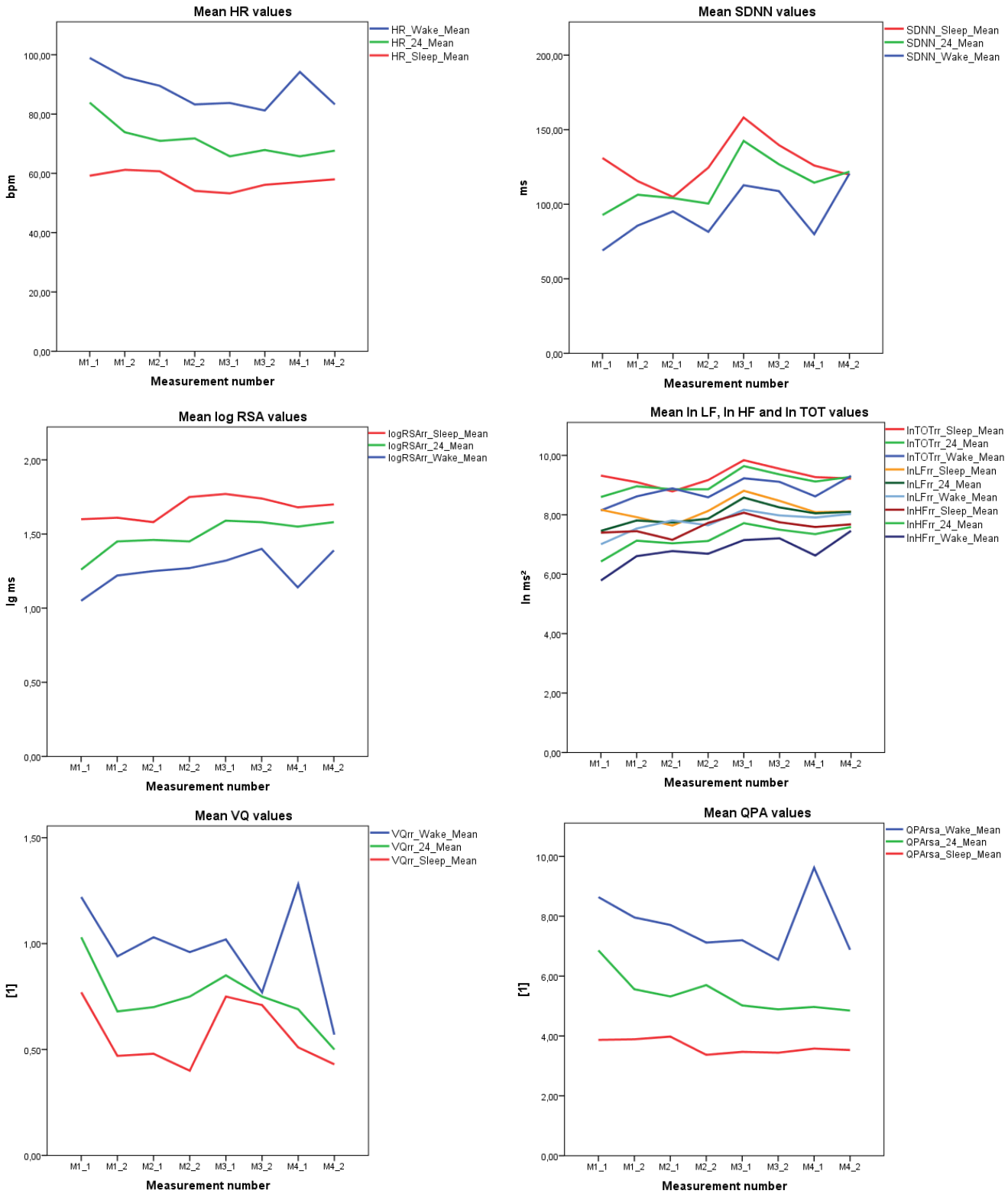


Figure 26: Diagrams of all Variables coded by Color (see figure 24)

4.2.3 Subject 803

Table 9: 803´s Measurement Segments

Number	Date	Number	Date
M1_1	01.05.12	M3_2	24.07.12
M1_2	02.05.12	M4_1	01.09.12
M2_1	09.06.12	M4_2	02.09.12
M2_2	10.06.12	M5_1	03.10.12
M3_1	23.07.12	M5_2	04.10.12

The next individual did five measurements over the course of his stay, which were each cut into two segments of sufficient length. The following quality control established that all the segments were admissible for the next stage, therefore we analyzed ten sets of data in his case, the highest number of valid segments associated with a single individual from this study, tied with the ten valid measurements of subject 809.

His CCGs had distinguishable sleep stages in his MSP, and he had a frequency band in his HF spectrum. He went to sleep between 5:34 pm and 8:54 pm and woke up between 3:50 am and 6:04 am, sleeping at least 8,28 and at most 11,41 hours.

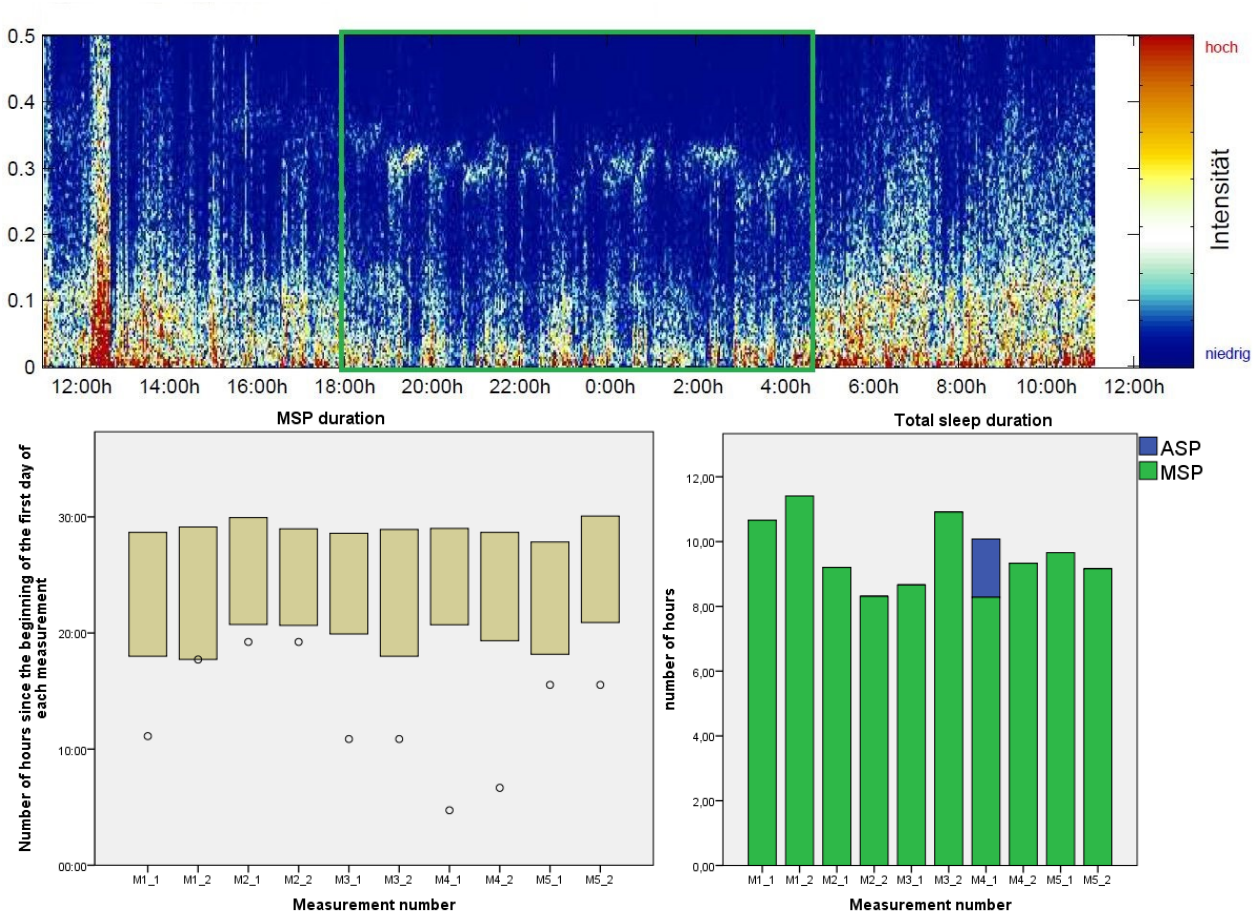


Figure 27: CCG, Sleep Duration and Distribution

His 24-hour mean HR ranged from 91,55 bpm (98th p.) to 101,61 bpm (100th p.), with a mean value of 96,15 bpm, while his sleep mean values ranged from 76,22 bpm (95th p.) to 86,74 bpm (100th p.), with an average value of 80,40 bpm. In both cases, his HR was abnormally high, never falling below the 98th and 95th percentile respectively.

His 24-hour mean values ranged from 39,25 ms (1st p.) to 61,23 ms (22nd p.) with a mean value of 49,28. Seven out of the ten segments had mean values at or below the 5th percentile. His sleep mean values ranged from 40,35 ms (1st p.) to 63,69 ms (18th p.), with a mean value of 51,17 ms and six out of ten values below the 5th percentile.

The 24-hour mean values had a minimum of 1,04 lg ms (13th p.) and a maximum of 1,29 lg ms (57th p.), with an average mean value of 1,18 lg ms, while the sleep mean values had a range of 1,17 lg ms (10th p.) to 1,51 lg ms (48th p.).

While the former ranged from 5,89 ln ms² (1st p.) to 6,84 ln ms² (33rd p.), his sleep mean values fluctuated between 5,71 ln ms² (1st p.) and 6,56 ln ms² (17th p.).

Ln HF on the other hand showed average or even above average results regarding its 24-hour mean values as well as his sleep mean values. They ranged from 5,20 ln ms² (22nd p.) to 6,50 ln ms² (82nd p.) as well as between 5,46 ln ms² (12th p.) and 6,90 ln ms² (65th p.).

Ln TOT returned to the trend observed in most other variables, in that it was far lower than average, as his 24-hour mean values had a minimum of 7,04 ln ms² (1st p.) and a maximum of 8,03 ln ms² (31st p.), while his sleep mean values were located between 7,03 ln ms² (2nd p.) and 8,02 ln ms² (23rd p.).

His VQ was another variable that fell far below average. While his 24-hour mean values ranged from 0,34 (2nd p.) to 0,70 (16th p.), his sleep values fluctuated between -0,34 (7th p.) and 0,19 (29th p.).

His QPA sleep mean values ranged from 4,30 (69th p.) to 4,83 beats per breath (90th p.).

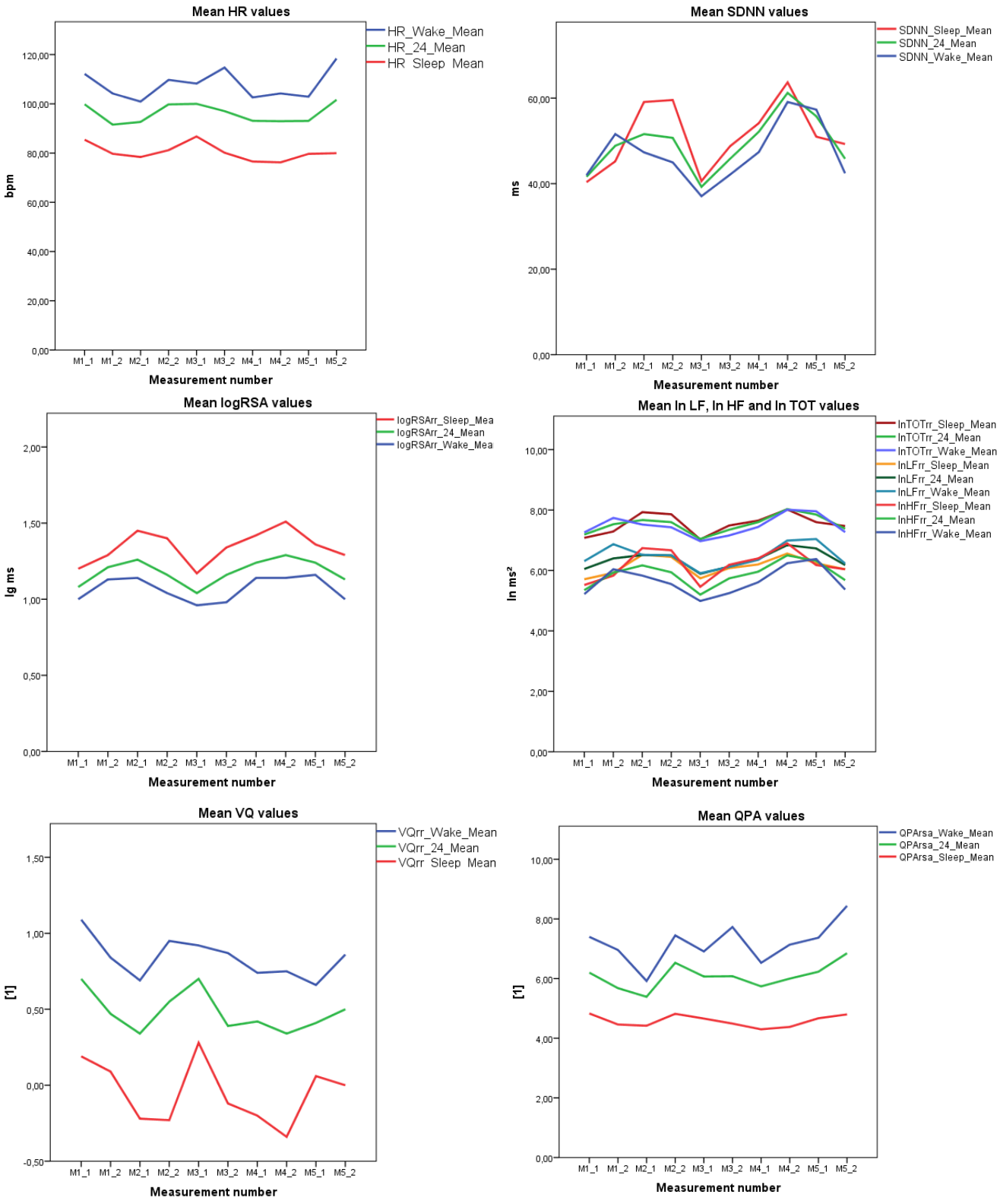


Figure 28: Diagrams of all Variables coded by Color

4.2.4 Subject 804

Table 10: 804´s Measurement Segments

Number	Date	Number	Date
M2_1	07.05.12	M4_1	16.08.12
M3_3	16.07.12	M5_1	09.10.12

Subject 804 did 6 different measurements, two of which were within the same week. They were cut into nine segments of appropriate length. In the end, five of the initial nine segments were declared invalid (see chapter 5.1), leading to a total of four different segments eligible for analysis. Those segments were M2_1, M3_3, M4_1 and M5_1. The segment M2_1 only had a length of close to 19 hours, as opposed to the 24 hours of the other segments. A noteworthy note is the fact that 804 was the first subject to not have an ASP in any of his segments.

Regarding his sleep duration and distribution, while he initially went to sleep at 9:47 pm and slept for 7,6 hours, in M3_3 he went to sleep an hour earlier and slept for 6,5 hours. However in M4_1 he slept from 9:59 am to 6:30 pm. This state was reversed in M5_1, where he went to sleep at 11 pm and woke up at 7 am.

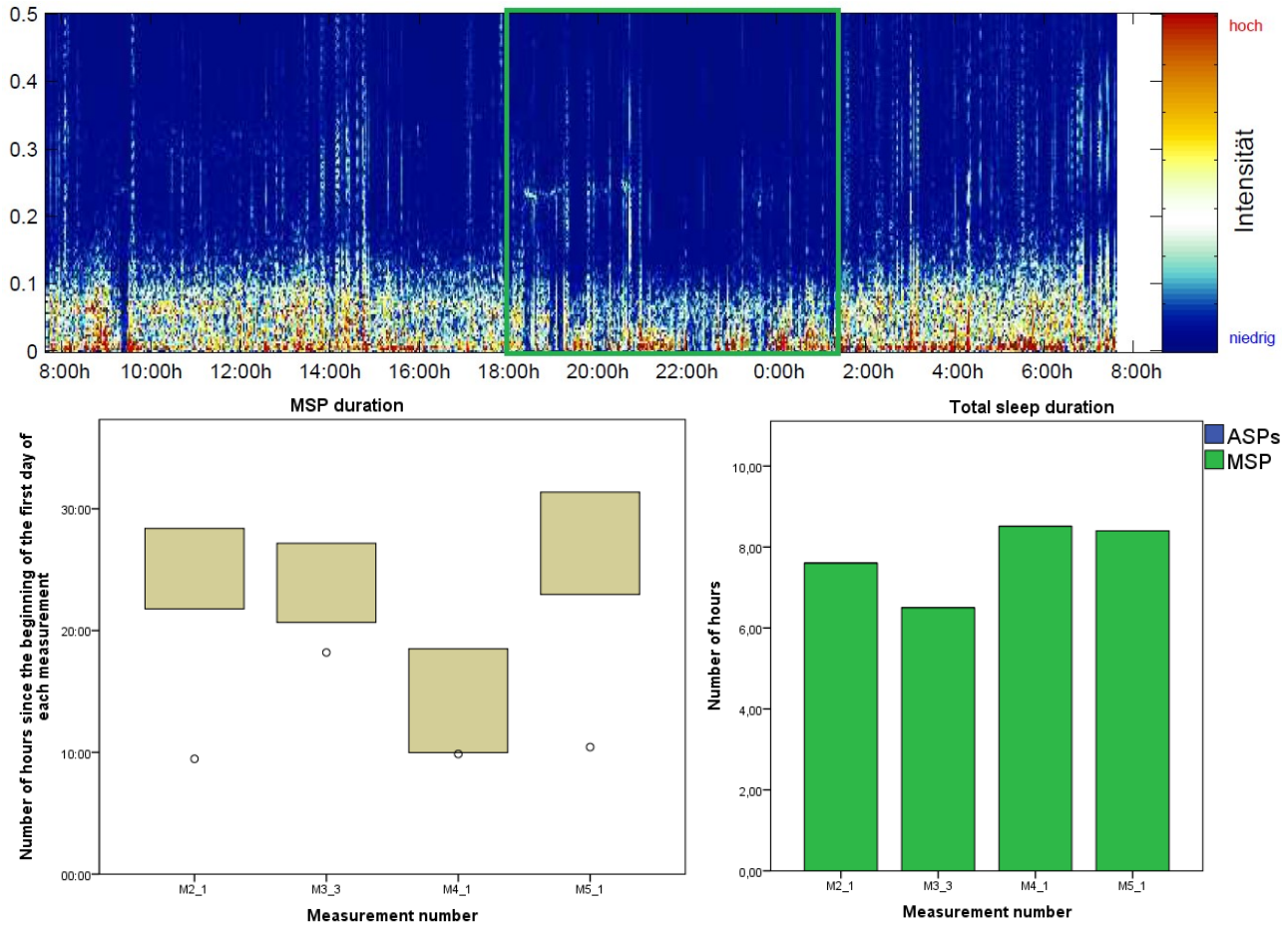


Figure 29: CCG, Sleep Duration and Distribution

His 24-hour mean HR increased steadily from 80,44 bpm (78th p.) in M2_1 to 88,39 bpm (92nd p.) in M3_3 and 96,66 bpm (100th p.), before returning to 86,03 bpm (88th p.) in M5_1. His sleep mean values were similar, in that the first three segments had values of 61,43 bpm (60th p.), 66,41 bpm (79th p.) and 89,00 bpm (100h p.) respectively, from which the HR decreased again to 68,77 (85th p.).

The 24-hour SDNN parameter had values of 66,67 ms (39th p.), 48,82 ms (9th p.), 26,12 ms (0th p.) and 51,87 ms (14th p.) in chronological order, while the sleep SDNN variable had even better mean values and a more marked drop in M4_1, with chronological values of 104,44 ms (85th p.), 82,88 ms (63rd p.), 24,41 ms (0th p.) and 77,50 ms (52nd p.).

His 24-hour log RSA mean values were 1,10 lg ms (25th p.) in M2_1, 0,98 lg ms (9th p.) in M3_3, 0,89 lg ms (4th p.) in M4_1 and 1,01 (12th p.) in M5_1, and the sleep mean values were 1,39 lg ms (48th p.), 1,24 lg ms (22nd p.), 0,89 lg ms (1st p.) and 1,20 lg ms (18th p.) respectively.

His ln LF 24-hour mean values were 7,08 ln ms² (57th p.), 6,46 ln ms² (15th p.), 5,06 ln ms² (0th p.) and 6,73 ln ms² (32nd p.) in chronological order, and his sleep mean values were 8,04 ln ms² (95th p.), 7,61 ln ms² (81st p.), 4,79 ln ms² ((1st p.) and 7,48 ln ms² (76th p.).

In contrast, the variable ln HF had 24-hour mean values of 5,12 ln ms² (30th p.), 4,50 ln ms² (12th p.), 3,09 ln ms² (1st p.) and 4,62 ln ms² (14th p.) as well as the sleep mean values 6,35 ln ms² (57th p.), 5,94 ln ms² (49th p.), 2,63 ln ms² (0th p.) and 5,88 ln ms² (44th p.).

Ln TOT had 24-hour mean values of 7,93 ln ms² (32nd p.), 7,40 ln ms² (7th p.), 6,11 ln ms² (0th p.) and 7,55 ln ms² (14th p.), while having sleep mean values of 9,01 ln ms² (88th p.), 8,66 ln ms² (78th p.), 5,83 ln ms² (0th p.) and 8,43 ln ms² (64th p.).

The first and only variable to break that trend was VQ. Its 24-hour mean values were 1,96 (86th p.), 1,96 (86th p.), 1,97 (86th p.) and 2,12 (91st. p.) in chronological order, while its sleep values were 1,69 (91st p.), 1,67 (90th p.), 2,16 (98th p.) and 1,60 (85th p.).

The final variable QPA followed previous trends and had sleep mean values of 3,44 (20th p.), 4,19 (62nd p.), 4,69 (81st p.) and 4,13 (59th p.).

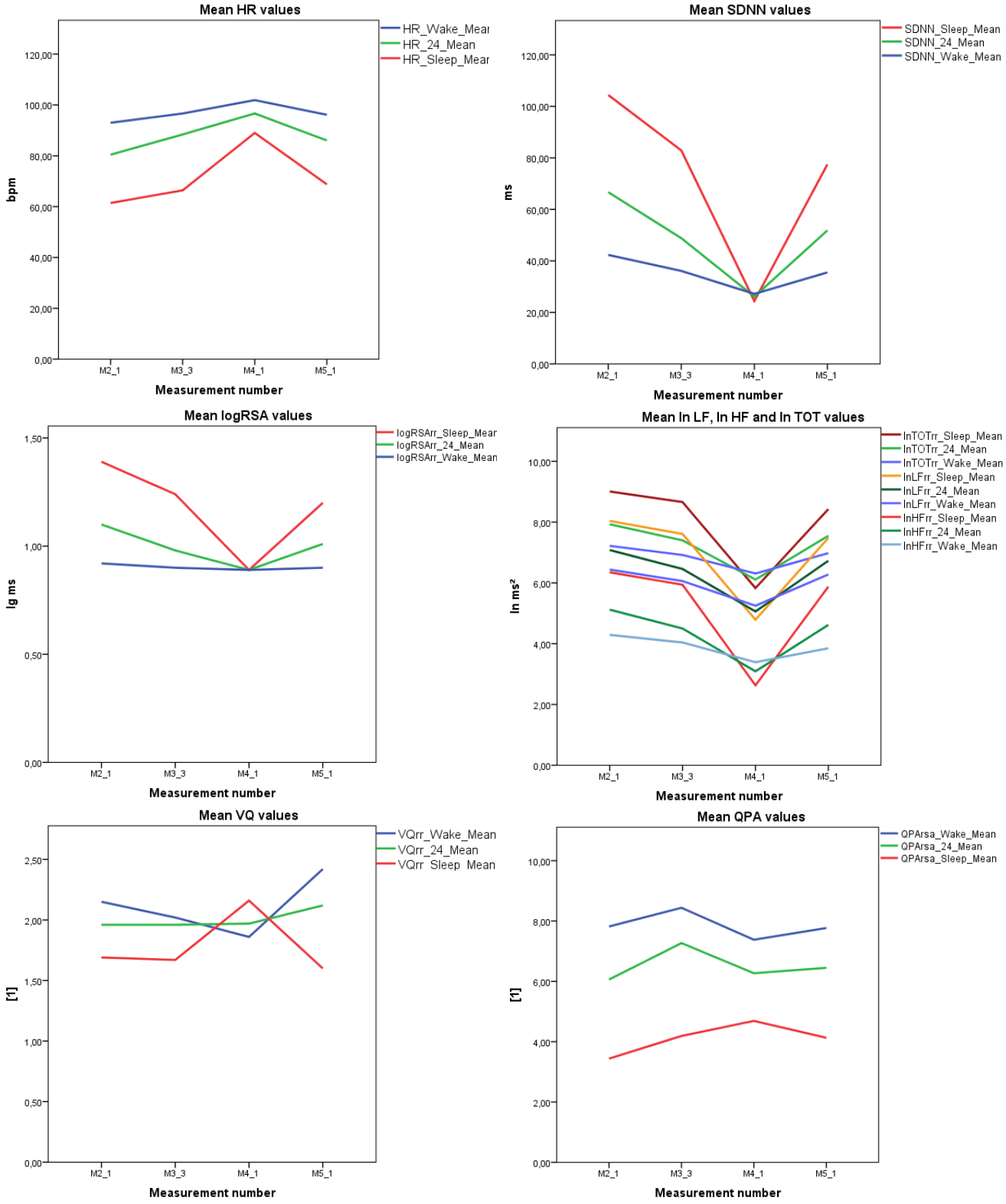


Figure 30: Diagrams of all Variables coded by Color

4.2.5 Subject 806

Table 11: 806´s Measurement Segments

Number	Date	Number	Date
M1_1	21.03.12	M3_2	10.08.12
M2_1	05.07.12	M4_1	18.09.12
M2_2	06.07.12	M4_2	19.09.12

Subject 806 had done 4 measurements from March to October, which were cut into 7 segments, the first measurement being the only one resulting in one segment, while the others were cut into two segments each. However the segment M3_1 was declared invalid due to quality concerns, leaving the subject with six valid points of data.

His CCGs showed no significant changes over time, his sleep and wake phases were distinguishable from each other by the intermittent character of the different sleep stages. He showed no signs of ASPs in any of his CCGs.

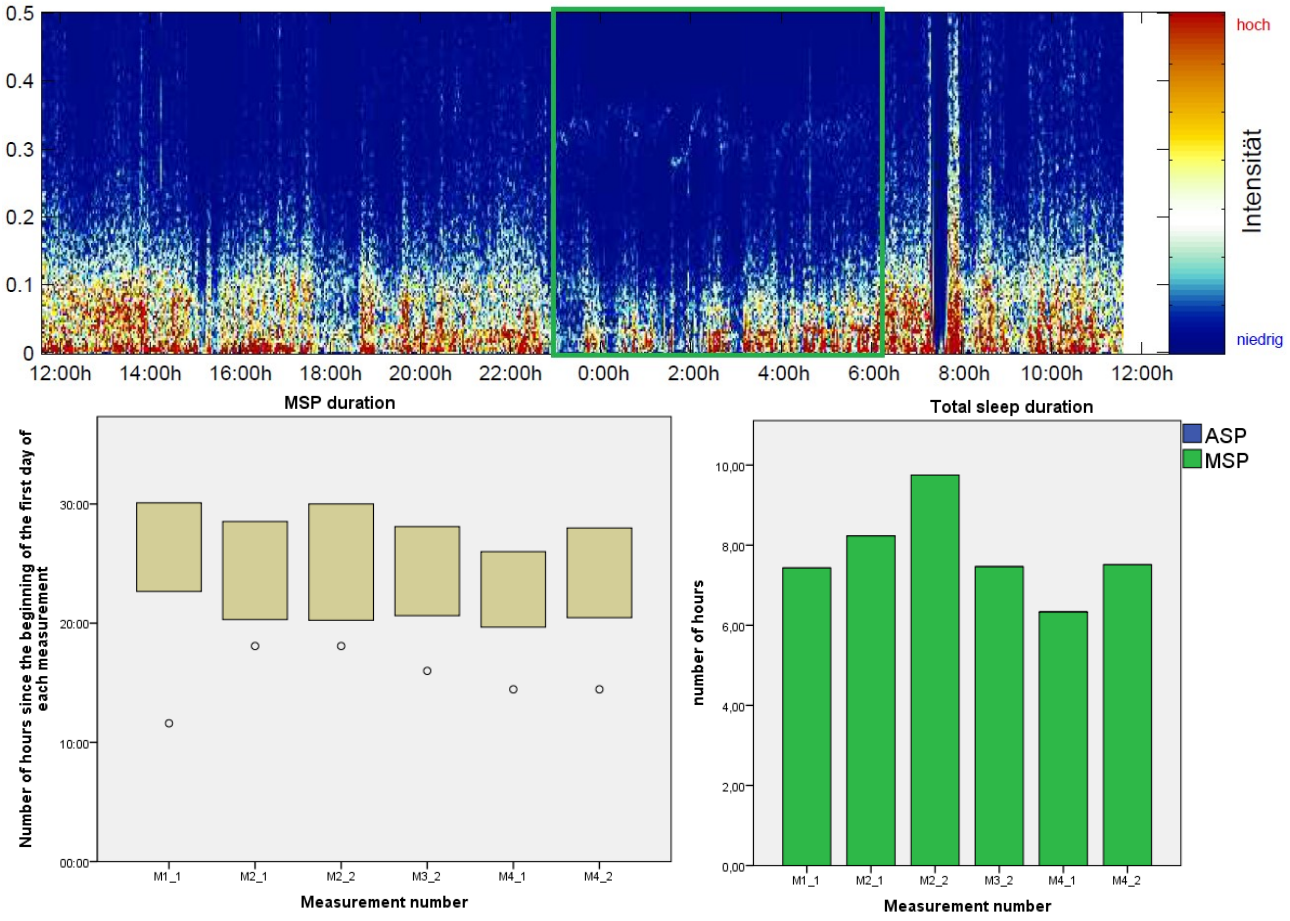


Figure 31: CCG, Sleep Duration and Distribution

His 24-hour mean HR had a minimum of 79,62 bpm (74th p.) and a maximum of 86,83 bpm (89th p.) in M4_1 and M4_2 respectively. In his sleep, his mean values fluctuated between 59,42 bpm (49th p.) in M4_2 and 67,96 bpm (82nd p.) in M2_2.

His SDNN values were smallest in M2_1 at an average of 72,20 ms (56th p.) and highest in M1_1 with a mean value of 80,32 ms (68th p.) over a 24-hour period. The sleep mean values had a minimum at 67,40 ms (34th p.) and a maximum of 90,80 ms (73rd p.) in M2_1 and M4_2 respectively.

His 24-hour mean values, which were located between 1,10 lg ms (25th p.) in M2_1 and 1,19 lg ms (42nd p. at 32 years of age in M1_1, 46th p. at 33 years of age in M4_1). His sleep mean values were not as constant, with values ranging from 1,20 lg ms (16th p.) in M2_1 to 1,43 lg ms (52nd p.) in M4_2.

His 24-hour mean ln LF values showed a downwards trend, from a maximum of 7,25 ln ms² (63rd p.) in M1_1 to a minimum of 6,88 ln ms² (42nd p.) in M4_2, it disappeared again in his sleep mean values, ranging from 6,37 ln ms² (14th p.) in M4_1 to 6,94 ln ms² (49th p.) in M4_2.

Similar results were also found in regards to the variable ln HF, where the 24-hour mean values started at the maximum of 5,44 ln ms² (43rd p.), then dropped to the minimum of 4,99 ln ms² (23rd p.) and afterwards stayed between those two values, whereas the sleep mean values stayed between 4,76 ln ms² (9th p.) and 5,79 ln ms² (38th p.) in M2_1 and M4_2 respectively.

Ln TOT´s 24-hour mean values were between 8,18 ln ms² (55th p.) and 8,46 ln ms² (73rd p.) in M4_2 and M2_2 respectively, while his sleep mean values fluctuated between 7,91 ln ms² (33rd p.) in M2_1 and 8,59 ln ms² (74th p.) in M4_2.

The lowest 24-hour mean VQ value was 1,66 (71st p.) in M4_1, and his minimum sleep mean value was 1,24 (71st. p.) in M4_1.

His heartbeat-to-breath ratio ranged from a mean 3,19 (13th p.) in M4_2 to 3,95 (48th p.) in M2_2.

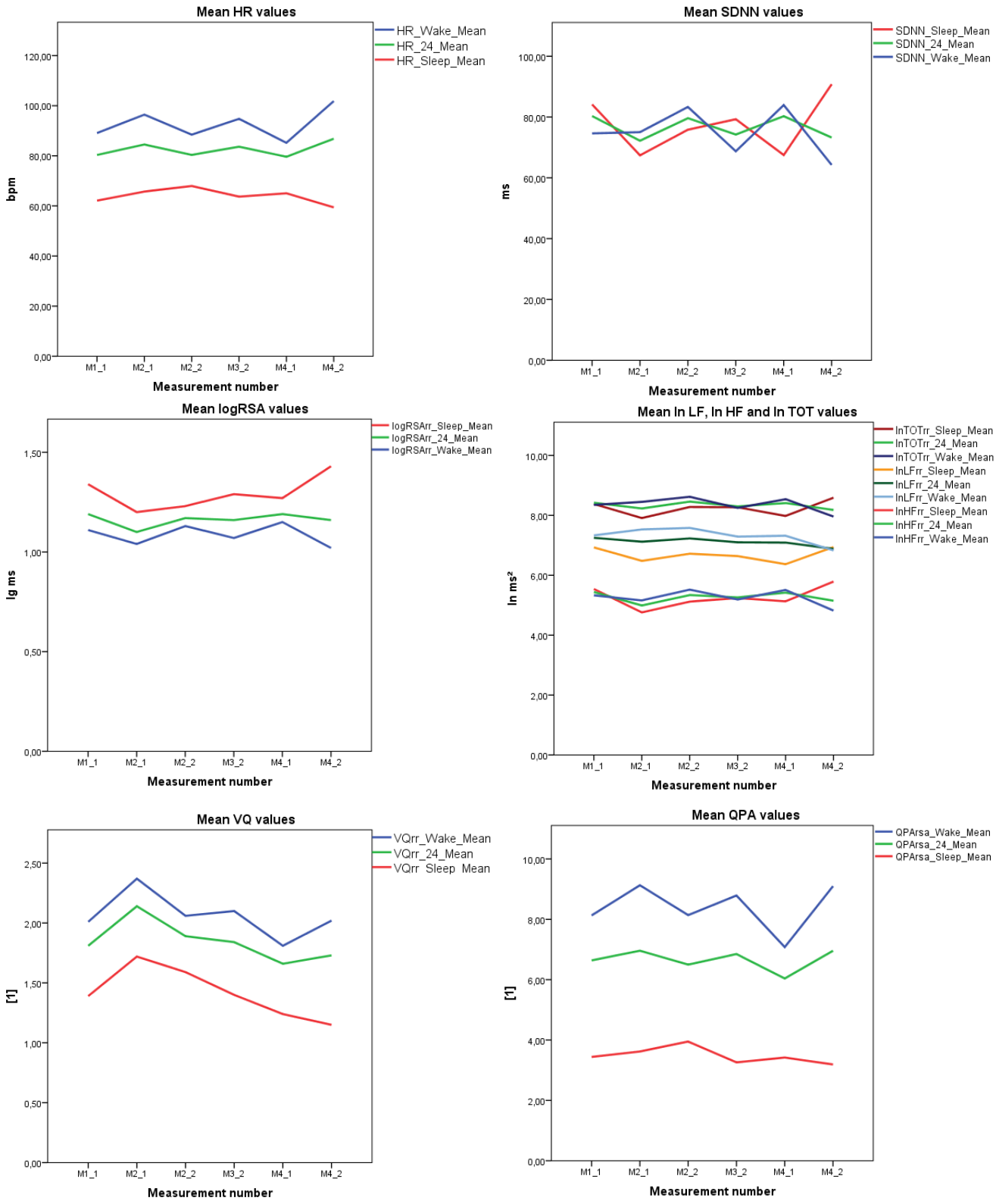


Figure 32: Diagrams of all Variables coded by Color

4.2.6 Subject 807

Table 12: 807´s Measurement Segments

Number	Date	Number	Date
M1_1	01.05.12	M3_2	24.07.12
M1_2	02.05.12	M4_1	01.09.12
M2_1	09.06.12	M4_2	02.09.12
M2_2	10.06.12	M5_1	03.10.12
M3_1	23.07.12	M5_2	04.10.12

Subject 807 did four measurements during his stay at Concordia station, which were cut into seven segments, with only the first measurement resulting in one segment, while the others provided two segments. The segment M4_2 was declared invalid due to an ASP that was longer than two hours, the other segments were all valid. He was the oldest member with the age of 55 years.

In his CCGs his active frequencies were all part of the LF band, and during his sleep there were frequency bands with equal distance to each other. The earliest time he went to sleep was 3 pm, while the latest was 10 pm, and he slept until 1 am at the earliest or until 5:30 am at the latest. His shortest MSP was in M3_1 with a duration of 6,00 hours, the next day in M3_2 he slept 9,98 hours, his longest recorded sleep phase.

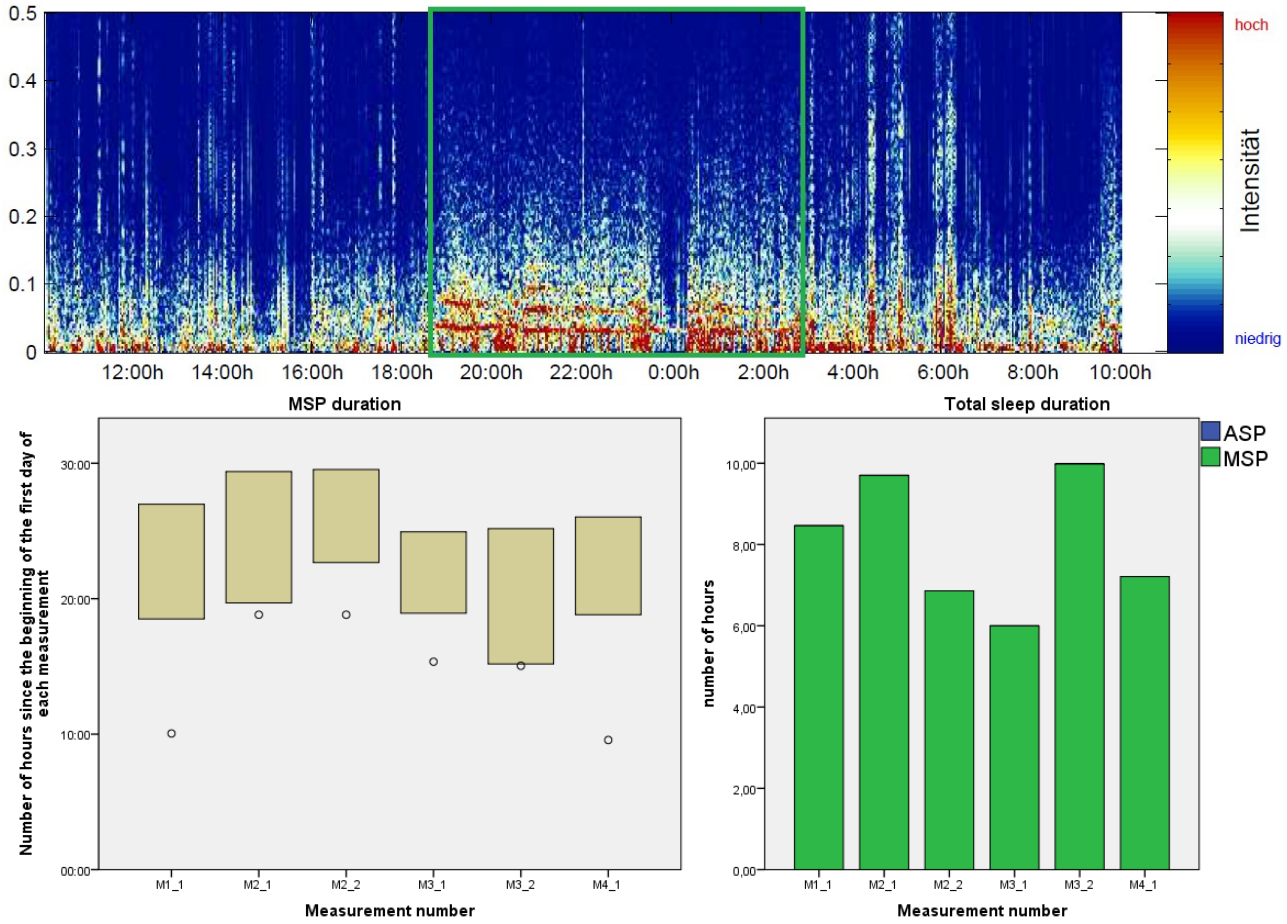


Figure 33: CCG, CCG, Sleep Duration and Distribution

His 24-hour mean HR started at 76,41 bpm (62nd p.) in M1_1, then dropped to the minimum of 68,11 bpm (17th p.) in M2_1, rose again to 76,59 bpm (62nd p.) in M2_2, 78,35 bpm (70th p.) in M3_1 and 80,17 bpm (73rd p.) in M3_2, before settling at 70,94 bpm (31st p.) in M4_1. His sleep mean values were 76,41 bpm (62nd p.), 68,11 bpm (17th p.), 76,59 bpm (62nd p.), 78,35 bpm (70th p.), 80,17 bpm (73rd p.) and 70,84 bpm (31st p.) respectively.

The SDNN mean values stayed above the 98th percentile for his age group over the course of the Antarctic winter, starting at 90,70 ms (98th p.) and 176,15 ms (98th p.) for his 24-hour and sleep mean variables respectively. In M2_1 his 24-hour mean values then rose to 109,89 ms (98th p.), while the sleep mean values decreased to 150,73 ms (98th p.). The next three segments had 24-hour mean values of 83,72 ms (98th p.), 83,21 ms (98th p.) and 83,89 ms (98th p.) respectively, with sleep mean values of 160,59 ms (98th p.), 160,47 ms (98th p.) and 150,52 ms (98th p.). The last segment M4_2 had respective 24-hour and sleep mean values of 97,28 ms (98th p.) and 175,93 ms (98th p.).

While the 24-hour log RSA mean values had a minimum of 1,15 lg ms (89th p.) and a maximum 1,31 lg ms (97th p.) in M1_1 and M2_1 respectively, the sleep mean values were even higher with values above 1,49 lg ms (96th p.).

His ln LF, ln HF and ln TOT variables showed no trend in regards to the time spent in Concordia, all 24-hour and sleep mean values were constantly above the 93rd percentile.

Neither his 24-hour nor his sleep VQ mean values ever dropped beneath 1,00, while his QPA had values of 4,30 (57th p.), 4,48 (61st p.), 4,77 (72nd p.), 3,64 (21st p.), 4,32 (57th p.) and 4,33 (57th p.) in chronological order.

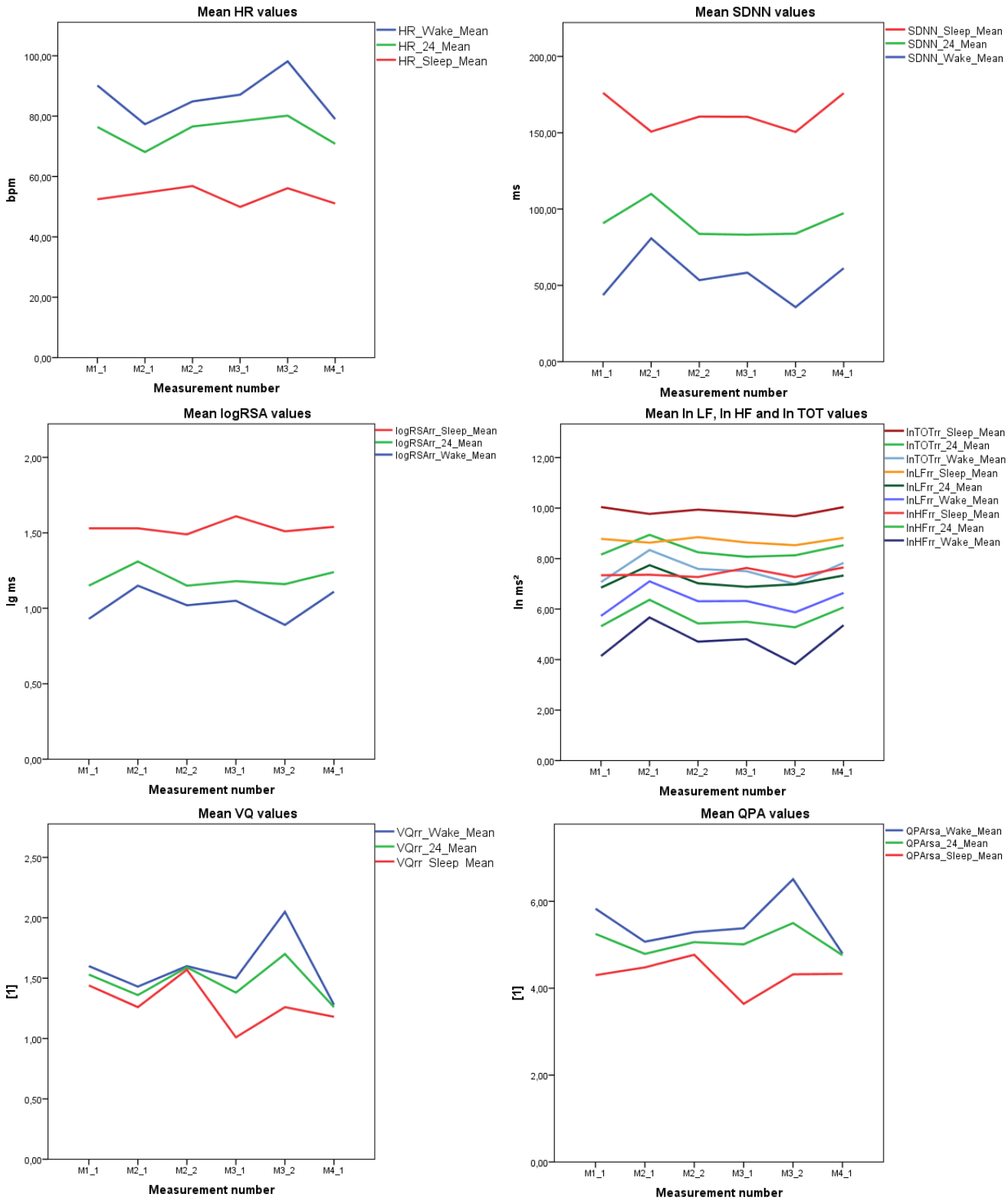


Figure 35: Diagrams of all Variables coded by Color

4.2.7 Subject 808

Table 13: 808´s Measurement Segments

Number	Date	Number	Date
M1_1	11.04.12	M3_1	22.08.12
M2_1	17.05.12	M4_2	30.09.12

Subject 808 completed four measurements during his stay at Concordia station, out of which came a total of six segments with sufficient length, with the second and fourth measurement resulting in two segments each, while the first and third ones only had enough data for one segment each. However two of those, M2_2 and M4_1, were declared inadmissible due to the overall quality of the segments, leaving 808 with four valid ones, M1_1, M2_1, M3_1 and M4_2.

He went to sleep between 6 pm and 7 pm and woke up between 1 am and 2 am in the morning, resulting in sleep durations between 6,70 and 8,03 hours with ascending chronological order. He also showed no signs of any ASPs in any of his segments.

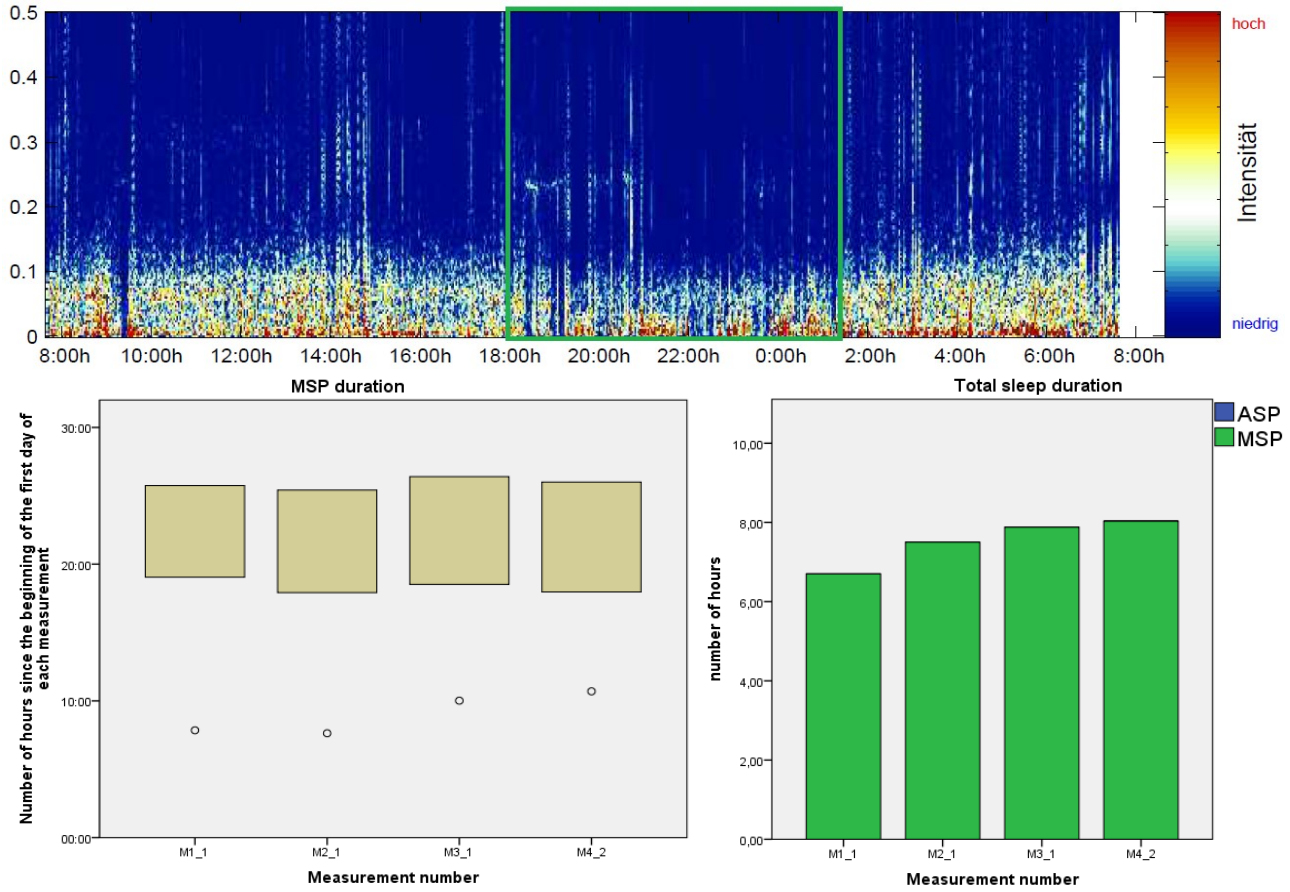


Figure 35: CCG, CCG, Sleep Duration and Distribution

His 24-hour mean HR was recorded in his first segment at 95,51 bpm (97th p.), then dropped to 91,58 bpm (94th p.) in M2_1, 89,21 bpm (92nd p.) in M3_1 and finally settled at 88,47 bpm (91th p.). However, the same trend was not present in his sleep mean values, which were 73,02 bpm (87th

p.), 76,63 bpm (91st p.), 69,87 bpm (79th p.) and 75,46 bpm (88th p.) in chronological order.

With 24-hour SDNN mean values of 41,31 ms (15th p.), 39,92 ms (13th p.), 46,23 ms (22nd p.) and 43,67 ms (19th p.) in M1_1 through M4_2 respectively. His sleep mean values were 51,65 ms (33rd p.), 42,22 ms (18th p.), 57,19 ms (40th p.) and 49,72 ms (28th p.).

His 24-hour log RSA mean values were 0,95 lg ms (23rd p.), 0,91 lg ms (15th p.), 0,96 lg ms (26th p. at age 49) and 0,96 lg ms (28h p. at age 50), while he had sleep mean values of 1,05 lg ms (22nd p.), 0,92 lg ms (9th p.), 1,06 lg ms (24th p.) and 1,07 lg ms (28th p.) in chronological order respectively.

His ln LF, ln HF and ln TOT were also always below the 30th percentile in all values apart from the sleep mean values of ln TOT, whose mean values reached the 32nd percentile. No trend in regards to time could be found in any one of those parameters.

The lowest 24-hour mean VQ value was 1,95 (75th p.) in M3_1 and its lowest sleep mean value was 1,15 (36th p.) in M4_2. His sleep mean QPA values ranged between 4,70 (73rd p.) in M3_1 and 5,06 (82nd p.) in M4_2.

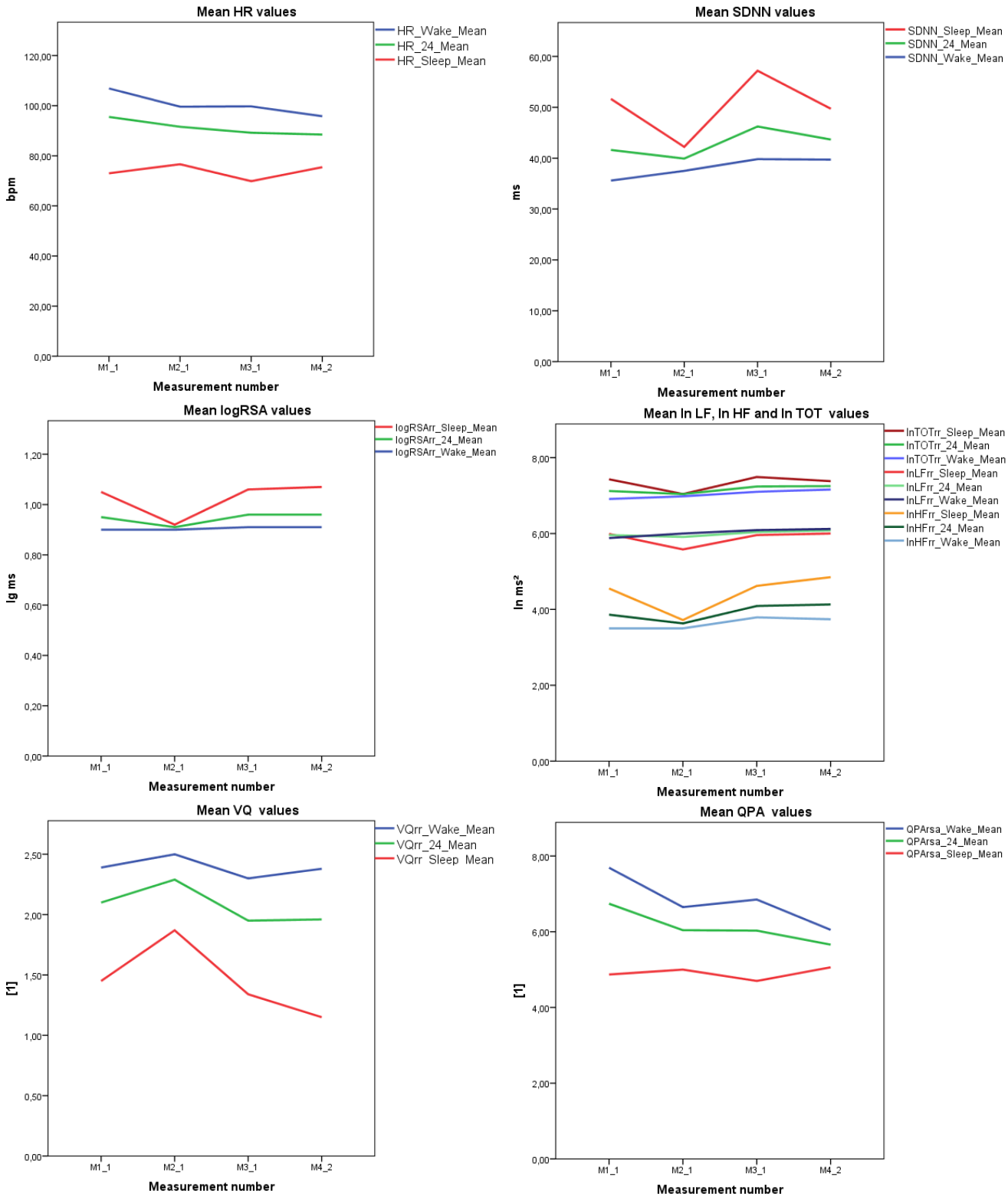


Figure 37: Diagrams of all Variables coded by Color

4.2.8 Subject 809

Table 14: 809´s Measurement Segments

Number	Date	Number	Date
M1_1	16.04.12	M3_3	27.07.12
M2_1	14.06.12	M4_1	05.09.12
M2_2	15.06.12	M4_2	06.09.12
M3_1	25.07.12	M5_1	11.10.12
M3_2	26.07.12	M5_2	12.10.12

Subject 809 was the only female individual in Concordia at the time and her six different measurements, two of which were within seven days of each other, resulted in ten different segments, with most measurements being cut into two segments. The first measurement resulted in one segment, while the third one was cut into three segments.

She went to sleep between 6 pm and 2 am and woke up anytime between 3 am and 9 am. She also slept longer on average the more time passed, however her sleep patterns did not improve with the resurgence of daylight at Concordia.

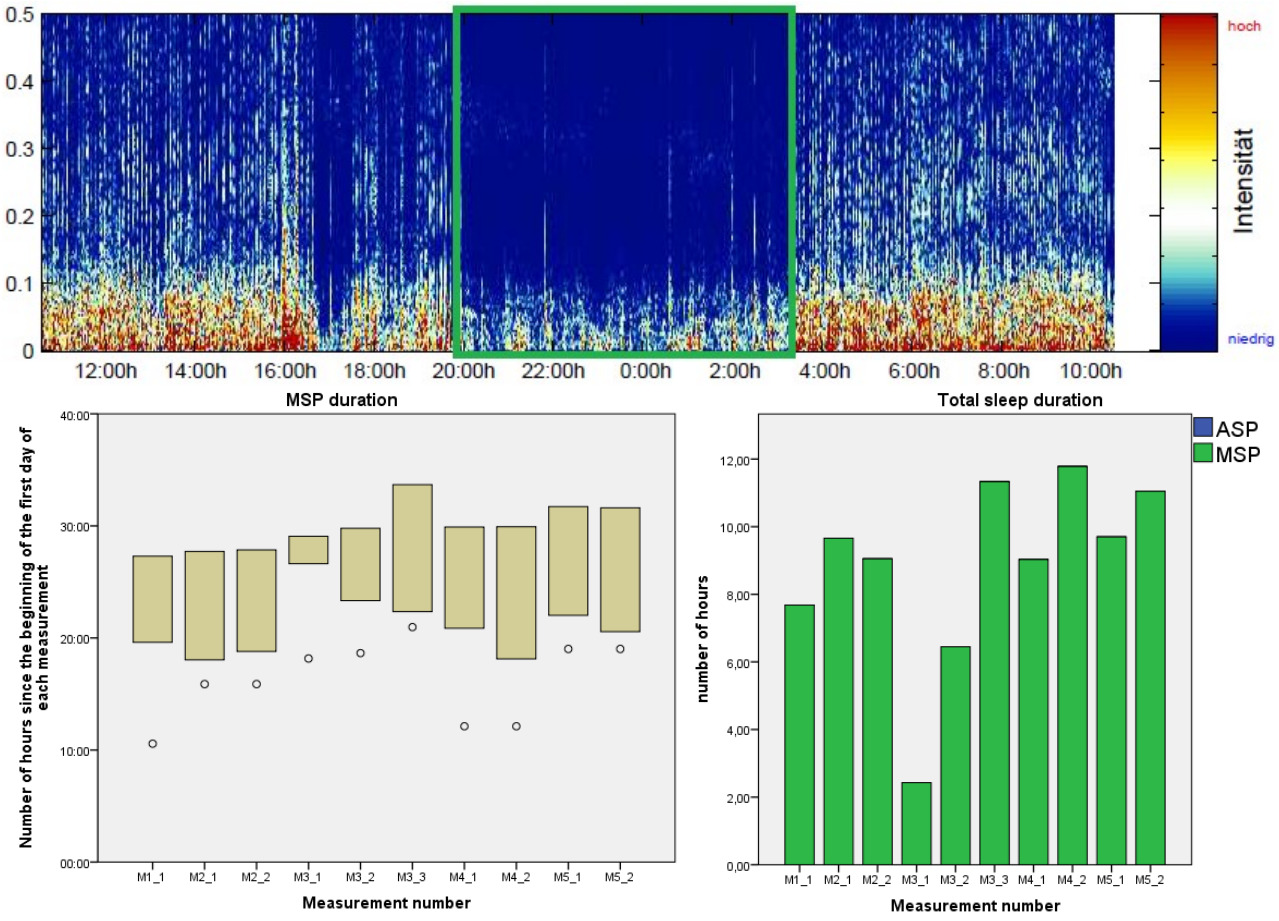


Figure 37: CCG, Sleep Duration and Distribution

Her 24-hour mean HR showed a downwards trend over time, with values ranging between

79,55 bpm (59th p.) and 85,34 bpm (82nd p.) in segments M1_1 through M3_3 and between 74,92 bpm (35th p.) and 81,47 bpm (69th p.) in the last four segments. Her sleep mean values were highest in the beginning with 76,26 bpm (88th p.) in M1_1 and decreased to 64,08 bpm (47th p.) in M3_3, while the last four segments rebounded and ranged between 65,36 bpm (58th p.) in M5_2 and 71,45 bpm (82nd p.).

Her SDNN variable showed a similar trend, in that her 24-hour mean values started at 37,36 ms (7th p.) in M1_1, rose to 39,19 ms (10th p.) and 47,52 ms (19th p.) in M2_1 and M2_2 respectively, before increasing the most in M3_1 through M3_3, with values of 38,06 ms (9th p.), 45,77 ms (17th p.) and 58,73 ms (50th p.). M4_1 and M4_1 remained on that level with values of 54,64 ms (39th p.) and 58,67 ms (53rd p.), while M5_1 decreased again to 39,97 ms (11th p.) before rising again to 55,97 ms (44th p.) in M5_2. His sleep mean values went from 32,60 ms (8th p.) in M1_1 to 38,12 ms (12th p.) and 48,84 ms (31st p.) in M2_1 and M2_2 respectively, before decreasing to the second lowest and highest values of 34,53 ms (9th p.), 49,10 ms (31st p.) and 63,32 ms (65th p.) in M3_1, M3_2 and M3_3 respectively. In M4_1 and M4_2 they were at 47,56 ms (28th p.) and 58,30 ms (54th p.) respectively, before the final values of 36,37 ms (11th p.) and 60,37 ms (62nd p.).

The 24-hour mean log RSA values were generally low, with the two highest ones being 1,14 lg ms (42nd p.) and 1,10 lg ms (29rd p.) in M5_2 and M3_3 respectively. The two lowest values were 0,96 lg ms (14th p.) and 0,97 lg ms (14th p.) in M3_1 and M1_1 respectively. Her sleep mean values ranged from 0,97 lg ms (7th p.) to 1,26 lg ms (38th p.).

The variable ln LF had a wide range of values, with a minimum of 5,44 ln ms² (8th p.) and a maximum of 6,78 ln ms² (75th p.) for his 24-hour mean values as well as a minimum and maximum of 5,05 ln ms² (6th p.) and 6,79 ln ms² (77th p.) for his sleep mean values.

The first six segments of the 24-hour mean ln HF values had ones from 3,94 ln ms² (6th p.) to 5,02 ln ms² (38th p.) and continued on to a range of 4,23 ln ms² (14th p.) to 5,04 ln ms² (39th p.) in his final four segments. Her sleep mean values ranged from 3,99 ln ms² (7th p.) to 5,48 ln ms² (42nd p.)

Ln TOT also expressed similar results with ranges from 6,88 ln ms² (8th p.) to 7,88 ln ms² (59th p.) and from 6,61 ln ms² (9th p.) to 8,00 ln ms² (74th p.) in his 24-hour and sleep mean values respectively.

Her 24-hour mean VQ values were above average with values of 1,25 (50th p.) in M2_1 and M5_2 to 1,83 (96th p.) in M2_2 and 0,66 (50th p.) in M2_1 to 1,39 (88th p.) in M4_2 for his sleep mean values. Her sleep QPA mean values were between 3,52 (18th p.) and 4,52 (74th p.).

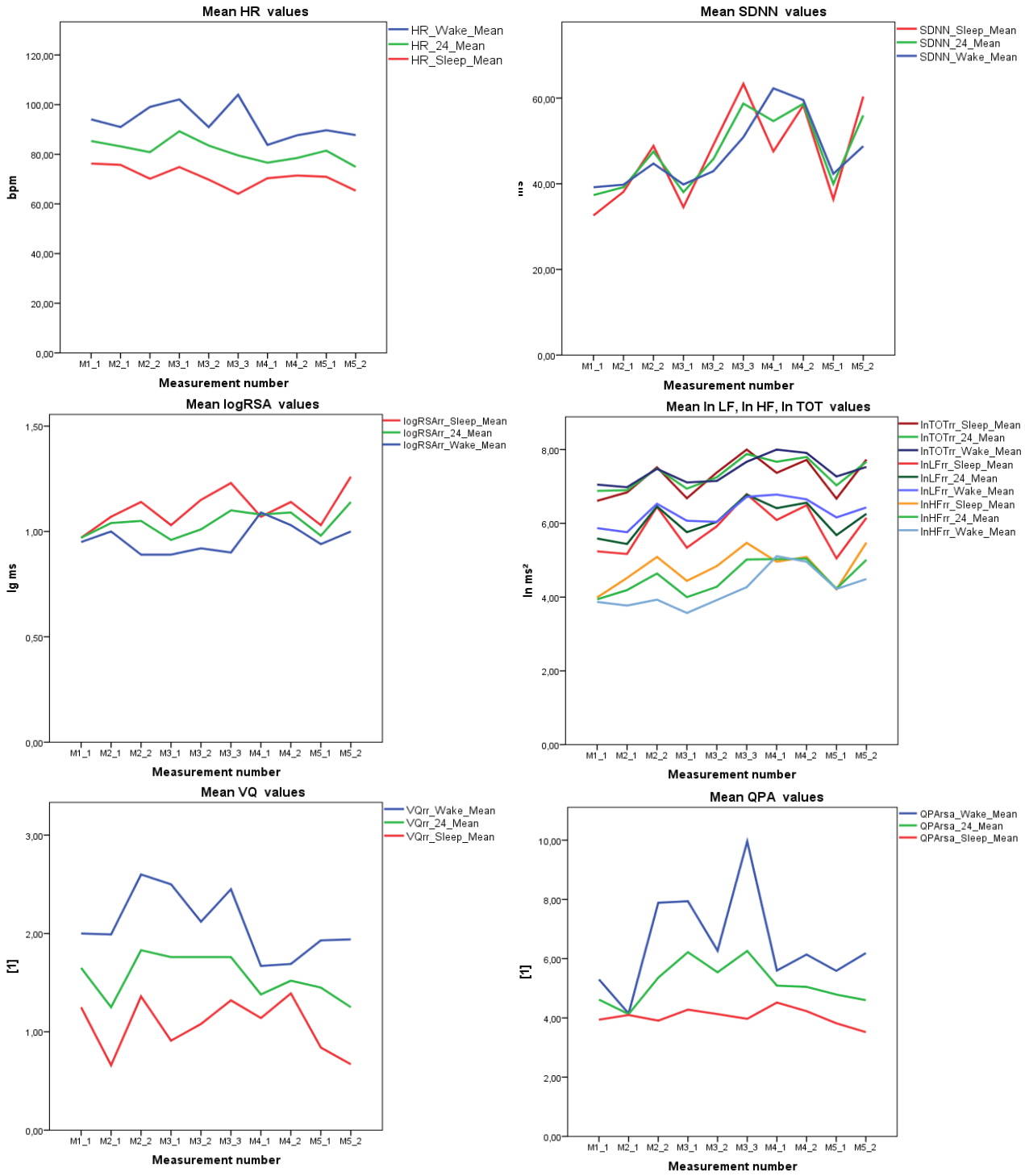


Figure 38: Diagrams of all Variables coded by Color

4.2.9 Subject 810

Table 15: 810´s Measurement Segments

Number	Date	Number	Date
M1_1	19.04.12	M2_2	08.06.12
M1_2	20.04.12	M3_1	20.08.12
M2_1	07.06.12	M4_2	22.10.12

Subject 810 completed 4 measurements during his stay, which were cut into seven segments of sufficient length. M3_1 was the only segment of the third measurement. The segment M4_1 was disqualified due to its overall quality, resulting in six valid segments, M1_1, M1_2, M2_1, M2_2, M3_1 and M4_2.

He went to sleep three times at approximately 3:30 pm, once at 7:07 pm and twice around 11 pm, while waking up between 8 pm and 5 am, leading to sleep durations between 3,23 hours and 11,60 hours long.

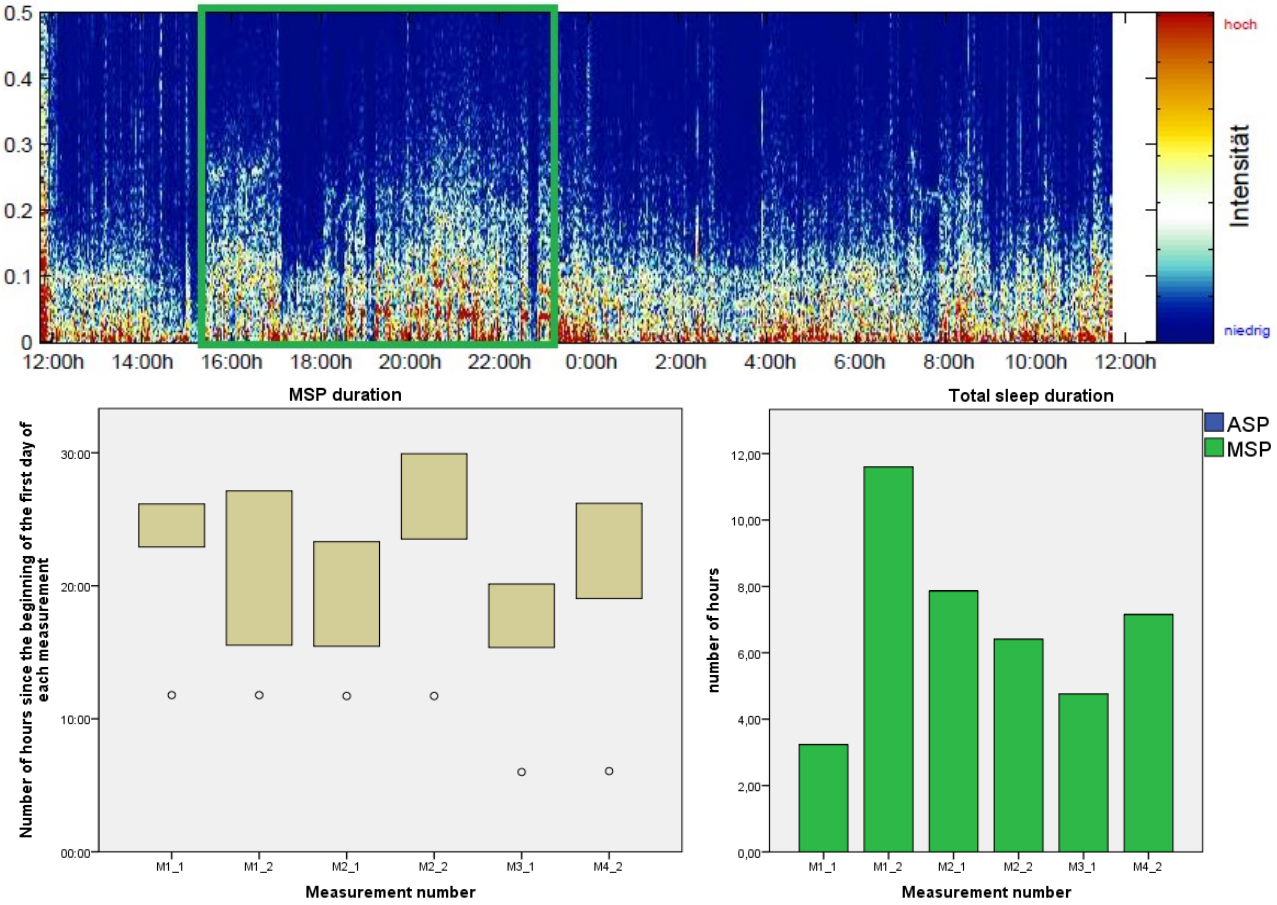


Figure 39: CCG, Sleep Duration and Distribution

His 24-hour mean values fluctuated between 76,59 bpm (61st p.) in M2_2 and 85,16 bpm (84th p.) in M1_1, while his sleep mean values ranged from 61,70 bpm (67th p.) in M2_2 to 78,53 bpm (97th p.) in M1_2.

SDNN showed more diversity in its values, with 24-hour mean values between 62,39 ms (23rd p.) and 80,38 ms (64th p.) in M3_1 and M4_2 respectively and sleep mean values between 57,84 ms (11th p.) and 103,69 ms (77th p.) in the same respective segments.

His log RSA values on the other hand were very low, with 24-hour mean values between 1,06 lg ms (16th p.) and 1,15 lg ms (27th p.) and sleep mean values ranging from 1,11 lg ms (10th p.) to 1,31 lg ms (28th p.).

Similar to SDNN, his ln LF values ranged between 6,82 ln ms² (32nd p.) and 7,51 ln ms² (75th p.) for the 24-hour mean values and between 6,85 ln ms² (30th p.) and 8,06 ln ms² (93rd p.) for his sleep mean values, while his ln HF values were below average for all but one of his valid segments, with 24-hour mean values of at least 5,03 ln ms² (18th p.) in M1_2 and at most 5,97 ln ms² (57th p.) in M4_2. His sleep mean values had a minimum in M3_1 with 4,95 ln ms² (7th p.) and a maximum of 6,76 ln ms² (58th p.). Through combining the two variables, ln TOT had 24-hour mean values between 7,85 ln ms² (22nd p.) and 8,49 ln ms² (66th p.) in M4_2 and sleep mean values of at least 7,69 ln ms² (12th p.) in M3_1 and at most 8,97 ln ms² (83rd p.) in M4_2.

Her 24-hour mean values were between 1,54 (65th p.) and 1,87 (90th p.) and his sleep mean values from 1,37 (83rd p.) to 1,90 (97th p.). His sleep mean QPA values ranged between 5,57 (96th p.) and 7,21 (100th p.).

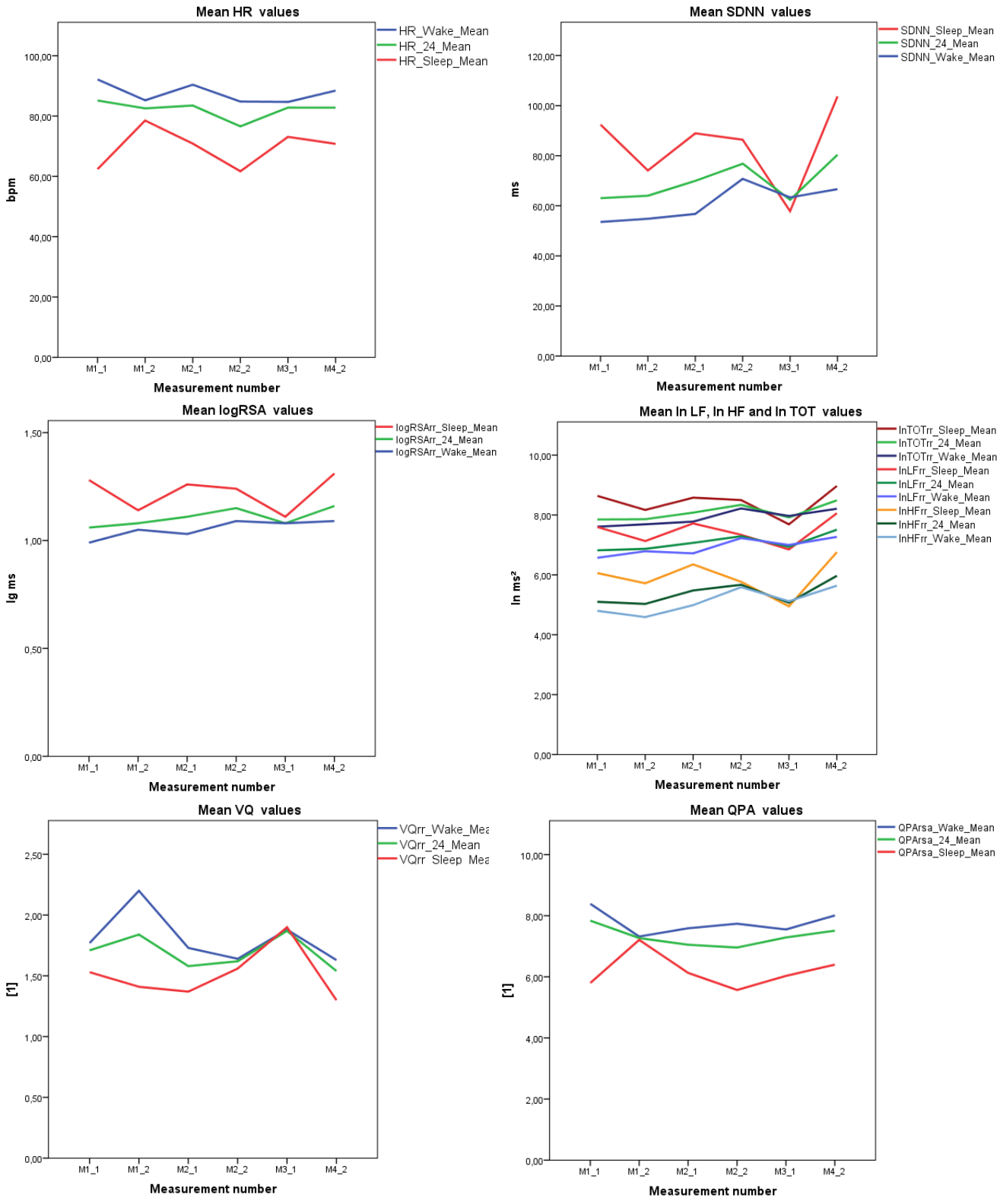


Figure 40: Diagrams of all Variables coded by Color

5 Discussion

We found no connection between HRV changes and the amount of time spent in Concordia. Every subject had their own trend in regards to their adaptation and autonomic function. And while there were individuals who showed an improvement at the end of the stay, no definitive link was found between these improvements and the return of sunlight to Concordia. In many cases, the differences in mean values were more present between measurements within the same period of seven days than between different measurement weeks. And while the day-to-day values changed dramatically, the overall trend was much more constant. There are several possible explanations for this phenomenon. It is possible that their daily activities and subsequent exhaustion thereafter left them with different constitutions than the day before or afterwards. Another possibility would be that daily values differ more greatly from each other due to other factors than simply their exposure time to the environment. These probably include emotional state of mind, physical exertion as well as interpersonal relationships. We also found that subjects reacted in various ways to the environment, with very contradicting results. While some had severe problems adapting to the environment, others had excellent HRV parameters during the entire stay. Additionally, the same could be said for hypoxia, as there were some who struggled with it at least for a period of time, while others never showed any signs of periodic breathing.

And even though the study could find no link between the time spent at Concordia station and ANS decompensation, it established the conclusion that there are ways to preserve HRV function even in such a harsh environment, and in the future it should be a priority to find out more about the coping mechanisms that play a role in this process.

5.1 Comparison to other studies

Never before has there been a study which analyzed the long term effects of isolation, extreme environmental conditions and hypoxia on HRV in a setting similar to Concordia. While there are several studies which have conducted similar tests on the continent of Antarctica, those were all done at stations located at the coast, whereas Concordia is far more isolated, not accessible during the winter and at an altitude of 3200 meters.

A study by Harinath et al. which was conducted at the Indian station Maitri compared a newly arriving team of scientists with a winter-over team which had stayed at the station for 12 months. It found that HRV parameters of the summer team returned to pre-Antarctic levels within a period of 60 days, while the winter-over team that had stayed for fourteen months showed significantly

higher HR and blood pressure results, as well as a shift of ANS function towards sympathetic activation (62). It showed that a prolonged stay adversely affected sympathovagal balance and increased LF activity while lowering HF activity. Our study did not find the same correlation and instead concluded that individual responses to the stimuli at Concordia play a much bigger role in the adaptation process than the amount of time spent there. The methodologies of the two studies also differed from each other, and due to the fact that Maitri station is located at the sea level near the coast, hypoxia was not a factor in the Harinath study.

Another study by Farrace et al. examined SNS activity through HRV measurements in 6 individuals located at Terra Nova Bay at three points in time, before the stay (baseline), at the beginning of the stay and after 40 days. Both HRV parameters and hormonal secretions were significantly lower in Antarctica compared with the baseline, indicating decreased SNS activity (63). In contrast, the study at Concordia did not analyze hormonal secretions as an indicator of SNS activity, and the HRV parameters were not measured before or at the beginning of the stay, but during said stay. Also the duration of the experiment at Concordia was several times longer than the one at Terra Nova Bay. Our findings in regards to SNS activity did not support the ones from the Farrace study, as the SNS activity was highly individual, and the differences in our methodologies could explain those differences.

Additionally, hypoxia has been shown to adversely affect sleep quality and the immune response(64,65), and in a study by Anderson et al. at Amundsen-Scott station, as many as 87 % of all expedition members reported symptoms associated with hypoxia, such as dyspnea, sleep deprivation, headache and dizziness in the first week at a high altitude (66). One study even found signs of hypoxia in subjects wintering over at sea level in Antarctica (67). Our means of recognizing and evaluating hypoxic effects on the subjects was through means of the frequency analysis of the CCG, which showed that several members of the winter-over team were chronically hypoxic, as evidenced by their periodic breathing. The rest however showed no signs of chronic hypoxia in their CCGs, suggesting that they adapted to the high altitude.

5.2 Individual results and interpretation

5.2.1 Subject 801

Subject 801 had no signs of RSA during his CCGs, instead his breathing was periodic, which is often observed in subjects at great heights under hypoxic conditions, indicating that 801 did not

adjust well to the high altitude of Concordia. His sleep duration was much shorter in his last two segments in October, which is possibly explained by the return of sunlight to Concordia during this time.

The data from every variable pointed toward the same trend: His first five data sets, from M2_1 to M4_1, were very similar to each other and showed very little change over time. The next two segments M4_2 and M5_1 generally had mean values that were below the previous minimal mean value in his SDNN, log RSA ln HF and ln TOT trends and above the previous maximum mean values of the HR and QPA variables. All the results mentioned above pointed toward less HRV and autonomic function. His VQ was the only exception, as the mean values of M2_2 were as high as those of M5_1, indicating that on that date, May 22nd 2012, he also had a shifted balance towards SNS activity. Note that during sleep, when the body should be resting, the only two times when his VQ sleep mean values dropped below 1 and therefore indicated some measure of rest, were at M3_1 and M3_2. In all the other segments, even his sleep was probably exhausting.

The last segment M5_2 showed a consistent deconditioning across all variables (for his sleep and 24-hour mean values), indicating a severe loss of autonomic function. Through these results, 801 demonstrated that the day-to-day changes of the HRV parameters played a more significant role than the chronic exposure to the ICE environment when it came to HRV loss.

In conclusion, this subject showed an increasing deconditioning of HRV parameters towards the end of his stay, however the most prominent change happened in the last segment M5_2, as M5_1 had values much closer to previous segments. Moreover, while there was a noticeable decline over time, it is doubtful that it was a result of his exposure to the Antarctic environment, as the most drastic changes in values occurred between the segments from the same measurement week, when the accumulated stressors varied by 24 hours. It is more likely that other factors played a role in autonomic regulation, and further research is necessary to discover those.

5.2.2 Subject 802

The next subject was coping with Antarctica´s environment very well, according to his values. He had an established routine regarding his sleeping patterns and he also never displayed signs of periodic breathing in his CCGs, meaning that he was well adjusted to the high altitude at Concordia. During his entire stay, his HRV parameters were above average, in most of his measurement segments he set the record for the highest recorded mean values of all the subjects. It is possible that he was already accustomed to harsh environments and high altitudes prior to his stay at Concordia, which would explain why his autonomic function was in such an excellent condition

during the entire duration of the experiment. While his sleep mean values did not show the same increase of HRV over time as his 24-hour mean values, they still support the hypothesis of his adaptation, as he maintained very high SDNNs and percentiles the entire period of his stay in Concordia.

The similarity between the first six variables HR, SDNN, log RSA, ln Lf, ln HF and ln TOT was not very surprising, as they are all various indicators for HRV and are therefore very likely to correlate in most measurements. However, the vegetative quotient does not necessarily follow that correlation, as it compares two different aspects of autonomic nervous system function and therefore shows how the sympathovagal balance influences the HRV. Those values were mostly at or below 1. This finding suggested that he had a very strong parasympathetic component to his HRV during his entire stay, and that it was particularly pronounced while he was awake, which is unusual, as one would expect the sympathetic component to be strongest during his wake period. It could mean that his daily activity involved very little physical exertion, or that he had problems concentrating and staying awake due to drowsiness. The latter explanation would furthermore explain his abnormally long sleep durations. Finally, his pulse-to-breath ratio had mean values of between 3,4 and 4 beats per breath, which can be interpreted as an excellent ratio for rest. In conclusion, it is remarkable how 802 managed to adapt physiologically to Concordia, however we do not know if he maintained these results well after Concordia or if they resulted from direct exposure to that environment.

5.2.3 Subject 803

Subject 803 had very contradicting results. His CCGs showed that his MSPs were structurally intact, the sleep stages were discernable from each other, and he had a strong component in the HF band, meaning that he experienced strong RSA. His sleeping habits, though varying, still suggest that he had a daily rhythm. These results point toward the conclusion that his circadian rhythm and autonomic function were present during his entire stay. In contrast, the HRV variables indicated a severe loss of HRV. These results suggested that there was barely any vegetative influence on his heart rate, especially during the sleep phase his heart rate should be much lower. Unfortunately it is unknown if such high levels could have been observable even before he came to Concordia, or if they were a direct result of his stay. Furthermore, there is no clear trend recognizable regarding the values worsening or getting better over time, pointing to the conclusion that these results were chronic even at the beginning of the expedition. The same loss of HRV was also noticeable in regards to his SDNN values. This again indicated that his overall variability was very low. The next variable

log RSA was the first variable that had some mean values around the 50th percentile or higher. This in turn indicated that his lessened vegetative function was sufficient to induce RSA. It also pointed towards a resistance to the high altitude and hypoxia. Ln LF continued the trend set by the first two variables by having very low values in both his 24-hour and sleep periods, with no clear association of the value height with the amount of time spent in Concordia, a finding consistent with previous results. Ln HF on the other hand showed average or even above average results regarding its 24-hour mean values as well as his sleep mean values. This finding was somewhat unexpected, as previous variables indicated that the overall variability, including the HF band, was severely diminished. It is possible that his RSA, which was stable despite the HRV loss, improved the ln HF values, as it is a contributing factor, however further research would be necessary to determine if that is a sufficient explanation. As ln TOT represents the total power of both LF and HF bands, it stands to reason that if LF was below average and HF was at or slightly higher than average, then the total power would fall below average, so this result was as expected. While these were quite low values in both periods, his low sleep VQ was healthy in contrast to previous below average results, as it stood for much stronger vagal activity than SNS activity, which is beneficial during sleep. However, in a healthy individual, the ratio should increase towards more SNS activity during the day, and that only marginally seemed to be the case. This was a finding similar to 802, and likewise, similar possibilities exist which would explain this result. While the QPA mean values are comparatively high ratios of heartbeats to breaths, they are not surprising considering his very high sleep heart rate. With an average of 80,40 bpm during sleep hours, it would mean his average respiratory frequency was between 17 and 19 breaths per minute, which is higher than usual during sleep, but it can be interpreted as an attempt to synchronize the heart rate and the respiratory frequency and establish a healthy ratio of the two during the night. In conclusion, 803 displayed signs of significantly lowered HRV and autonomic function, however his vagal activity was still more pronounced than his sympathetic activity. Additionally, his circadian rhythm was still mostly intact despite the altered photoperiodicity in Antarctica.

5.2.4 Subject 804

His CCGs were remarkable in that they did not resemble each other over time, a hitherto unique feature among the test subjects, as all previous subjects displayed very similar frequency profiles across time, whereas 804 had very different CCGs in the middle of his stay compared with those of the final month. The only common denominator was the missing RSA frequency band in the HF spectrum of the CCG, indicating he had trouble with the hypoxic conditions at Concordia.

M2_1 displayed very similar sleep and wake phases, they were almost indistinguishable from each other based on the frequency profiles alone and were instead determined by looking at the acc.edf-files which recorded his movements. By looking at his sleep phase more closely, there were hints of periodic breathing in the small spaces where he was in non-REM sleep stage. It confirmed his difficulties with the reduced oxygen supply in the air. Another interesting observation was that half of his wake phase, namely between 3 pm and 8 pm, showed very little activity in any frequency, even less than what one would expect to find in a normal sleep phase. This suggested that his autonomic function and therefore his HRV was very low. By the time he did the measurement for the segment M3_3 his CCG had improved somewhat, as it was easier to separate the wake and sleep phase. In the latter the periodic breathing was more pronounced than in the previous segment, suggesting that his alternative respiration was more expressed. However there were still periods of time when there was hardly any activity in the entire frequency spectrum, which occurred without a recognizable cause during his wake phase.

M4_1 was the most unusual and alarming of the segments. Apart from a five-hour period between 1am and 6 am, there was almost no activity, the entire segment was devoid of most HRV influences. There were no differences between the different sleep stages and the sleep and wake phase themselves could not be separated except for the QPA and acc.edf data. This progression of HRV loss indicated that it was a direct result of his stay in Concordia. The final segment M5_1 showed that his physiology was slowly recovering from the hardships of the previous months, as his CCG improved markedly compared to the previous ones. His LF activity returned and provided excellent separation between his wake and sleep phase, as did the periodic breathing present in the latter. While he still seemed to struggle with the hypoxia there, his overall physiological condition seemed to improve markedly with the return of sunlight to Antarctica.

Based on the CCG, it could be expected that his HRV variables would worsen over time until M4_1, after which his values should be improving. He also lost his circadian rhythmicity in M4_1, which he regained in his next segment. And indeed, the variables seemed to confirm the initial prediction regarding the behavior of the HRV parameters. In every variable, the first segment M2_1 had the best HRV values, which dropped slightly in M3_3 (with an increased HR, VQ and QPA). The segment M4_1 was by far the worst in regards to autonomic function, as all values plummeted from previous levels to or below the fifth percentile, while HR, VQ and QPA values increased to or near the 100^{th} percentile. This could mean that he experienced severe deconditioning due to the prolonged exposure to the ICE environment at Concordia. Once the sunlight returned in M5_1, his values also improved to or near the levels of M3_3, indicating that his values were recovering.

Unsurprisingly, his log RSA values were also very low considering his missing RSA band and the periodic breathing in his CCG. In the case of his VQ, both his 24-hour and sleep mean values were very high, indicating that his SNS was dominant. His QPA showed a similar trend, which pointed to the conclusion that his pulse-respiratory ratio was also affected by the HRV loss.

5.2.5 Subject 806

Apart from his first segment, where he went to sleep at 10:45 pm, subject 806 was keeping his daily routine, which was probably to go to sleep between 7:40 and 8:40 pm, though he woke up at different times in the morning, between 2 am and 6 am, resulting in varying sleep durations. By examining his variables, it was apparent that there were no recognizable trends regarding his HRV parameters. As was the case with other subjects, the difference between values was often greater between segments of the same measurement than between the different measurement weeks. His ln LF 24-hour mean value showed a downwards trend, however undermining that trend is the big difference in values within the same measurement week, suggesting that the trend is either coincidental or a result of other factors than time spent in Concordia.

His VQ showed a massive dominance of his SNS over his PSNS activity and never below 1, indicating that his SNS was active during his sleep phase as well, which would negate any restful effects the PSNS might have had during this time. On the other hand, the synchronization of his HR and respiratory frequency was still intact during sleep, indicating that while his SNS was overshadowing his PSNS, the latter was still active.

5.2.6 Subject 807

His CCGs indicated severe disruptions in his circadian rhythm and periodic breathing. It was the only way to distinguish his wake and sleep phases, which were also missing any characteristics regarding the different sleep stages, his non-REM sleep stages were not visible in any CCG. The circadian disruption was further evident in his sleeping patterns. He had irregular sleeping habits and slept between six and ten hours independent on the month of the measurement. Despite these initial indications that he lost his circadian rhythm, based on his variables his autonomic function was still intact. His SDNN values were especially high. Both his 24-hour and sleep mean values were above the 98th percentile the entire time he was staying at Concordia, with values between 83,21 ms and 109,89 ms in M3_1 and M2_1 respectively for his 24-hour mean values, and from 150,52 ms to 176,15 ms in M3_2 and M1_1 respectively for his sleep mean values. The latter were also the

highest absolute mean values measured in any individual during the stay, 802 was the only one to come within the range of those values, and he had half the age of 807, making his values even more remarkable. Even more surprising was his log RSA variable, which showed similar results to SDNN despite not being present in any of the CCGs.

His ln LF, ln HF and ln TOT variables all similarly indicated very high HRV in both his 24-hour and sleep mean values, which were all above the 93rd percentile. As was the case with all the previous variables, they did not show any trends dependent on the passage of time at Concordia.

The VQ was the first variable to show results which pointed towards bad sleep quality, suggesting that his SNS was more prominent than his PSNS, even in sleep. His QPA on the other hand was just slightly above average, with all but one value being above 4,30 (57th p.).

In regards to autonomic function, it can be established that subject 807 was in very good shape, especially for his age, however his circadian rhythm was severely disrupted and he also struggled with the hypoxic conditions at Concordia.

5.2.7 Subject 808

On his CCGs a trend can be seen towards better sleep quality. While there was hardly any difference between the wake and sleep phase, the two most recognizable being the lowered intensity in the LF band as well as a few instances of RSA, in M3_1 the beginning of the sleep phase is clearly marked by the beginning of a non-REM sleep stage, however as the night progressed the differentiation between the sleep stages became more blurred, and in M4_2 it was hardly noticeable over the time of the entire sleep phase. His sleep durations suggested that his circadian regulation was intact, as he kept a routine of his sleep hours.

Despite his intact circadian rhythm, his variables indicated that his HRV was either decreased or very low from the beginning. While this could be partially explained by his age of 49/50 years, his percentiles were still leaning towards the edges of the distribution spectra. However he did show signs of improving his parameters over time.

His 24-hour mean heart rate seemed to decrease over time, however taking into consideration the differences in values of the same measurements seen in previous subjects, it should not be construed as a trend caused by the passage of time at Concordia, as the downwards trend was very slim, and also not supported by the sleep mean values or other variables (see Fig. 37). Just as his HR values were high, so were his SDNN low. All the other variables were also below average for his age group. His VQ leaned heavily towards the SNS, however in the case of sleep values that was not very uncommon as seen by the low percentile number. His QPA was also slightly above average during

night time hours. All these results point to the conclusion that subject 808 had severe HRV dysfunction, which changed only marginally over time, despite his maintenance of a clear circadian rhythm.

5.2.8 Subject 809

As the only female participant in the study, the results from her measurements could provide interesting insights into the differences between genders in HRV regulation in an ICE environment.

Her CCGs were very peculiar, as her wake phases showed many disturbances, probably due to bad electrode contact. It seemed more difficult for her to keep the electrodes attached to her skin. Her sleep phases on the other hand were very clear, albeit almost void of any signals compared to the other CCGs. With no RSA band and severely diminished signal intensity during the sleep phase, she seemed to experience a loss of HRV as well as circadian disruption. This is further supported by the lack of any recognizable changes between her sleep stages, as her sleep phases all looked very uniform. The circadian disruption is further evident in her sleep patterns. Her sleep times and durations were very inconsistent, and her circadian rhythm showed no signs of improving with the return of sunlight in September and October, suggesting that either it took a longer time for her to readjust to it, or her sleeping patterns were influenced primarily by other factors than time or daylight.

While some variables showed a trend towards improvement of HRV parameters over time, the most marked differences in values were registered between segments of the same measurement week and not in between the weeks themselves.

Her low log RSA values proved consistent with the missing RSA band from her CCGs. Ln HF had similarly narrow ranges as her log RSA values, though it had a similar trend to her HR and SDNN values. As was the case with those two parameters, the sleep mean values did not show the trend as strongly as her 24-hour mean values.

His VQ indicated that 809 was under a lot of stress. On the other hand, her vegetative regulation was still intact, as was evidenced by her QPA values.

5.2.9 Subject 810

His CCGs were particularly severe, most were completely uniform, with no distinction between wake and sleep phases, or even various activities during the day. Even his QPA, usually a very dependable way of separating the wake and sleep phases, was very erratic during his sleep,

suggesting a severe vegetative imbalance. The segment M2_2 was the only one with a clear sleep phase and visible sleep stages. The high activity in the LF spectrum and the missing HF band indicated that his SNS dominated his heart physiology, however there was no indication of periodic breathing.

The high variance of his sleep phases lead to the conclusion that he had lost any sense of his daily rhythm in Antarctica, if he even had had any at all from the beginning. Taking into consideration the severity of his vegetative dysfunction, it was surprising how consistent his HR values were. However, other than his heart rate, the other variables showed a wide range in his values and percentiles. Two of his segments showed the most HRV degeneration, M1_2 and M3_1. In both segments, the variables indicated that his HRV was at a low point, and in the other segments the values improved considerably. This could be due to his activities and daily rhythm. His VQ supported the initial suspicion of proportionally high SNS activity at the time of each measurement, and his QPA sleep mean values confirmed his bad sleep quality. In conclusion, subject 810 showed no autonomic adaptation to Concordia and no trend of improvement or deterioration correlating with the time spent in Antarctica.

5.3 Limitations

There are also several setbacks that adversely affected the study in regards to its methodology and conclusion which need to be addressed.

First and foremost, the participation in this project was voluntary the entire time, and the adherence to the study proposal was limited. Not only were most measurements recorded without the actual ECG data and with various measurement lengths, but the activity protocols which were originally one of the most important features of this study, were never filled out. Had this not been the case, it would have been possible to differentiate between several daily activities instead of only focusing on sleep and wake times, and they could have provided an explanation for the big differences in the segments of the same measurement week. This was also one of the main reasons why it was not possible to conduct proper analyzing statistical methods. For future studies, the cooperation of the winter-over team has to be the top priority if we hope to gain more insights into the psychological and physical conditions of the subjects during their stay.

Secondly, several measurements had to be excluded due to various factors, including their length, quality and sleep phase distribution. As the program which was used to upload and calculate all mean variable values could only analyze one sleep phase at a time, a few measurements in which the subjects were decompensating the most had to be excluded as well. Therefore, in some subjects

it is possible that the variable trend would have shown different results than shown above. However it should be noted that less than half of the subjects had such measurements and that they were recorded at various points in time during the stay, making a connection with the duration of the expedition very unlikely.

Though the results of the existing segments would not have changed if the study had been carried out as described, the interpretation of said results would probably have been much easier.

5.4 Conclusion

Despite its limitations, this study is groundbreaking in several ways and may prove invaluable in the study of long term adaptation of the autonomic nervous system to ICE environments. It showed that the individual response to the same environmental conditions could vary significantly, and that there are ways to adapt physiologically. It also demonstrated that the results differ greatly from day to day due to several possible factors, and that those short term changes could have a big impact on the resilience of the subjects. More research is recommended to study the effects of those fluctuations on the overall health and productivity of the team members.

6 Literature

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