University of Twente

Mars Project

University College Twente

One giant leap for healthcare: monitoring health in extraterrestrial settings

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Contents

1 Abstract

As the world expands and people hope to colonize nearby planets in the near future, astronauts have become the closest example to what life could be like in space. Even with training, these astronauts still face health problems, which may or may not be detected overtime. This proposed paper will respond to the need of improving the health care systems for astronauts and outer-space settlers, in particular future Martians. The proposed research aims to form a vision of the most suitable wearable health technology for use in extraterrestrial conditions, in terms of the variables that are necessary for the device to monitor. These variables may be either biological signals or environmental signals. The system for monitoring mental health is also to be formed by this research. The main focus for mental health problems is on those that deal with stress. The research will define the point in which stress levels may become fatal. This research also looks into the analysis and interpretation of the signals and data obtained from the measurement device in order to form a theoretical framework for an ideal device for use in extraterrestrial environments. Through early detection, immediate action can be taken to prevent any fatalities. This research is not only useful for the health of astronauts and future space settlers, but it could also potentially help improve the current knowledge in health technologies on Earth. The steps taken in this research will result in one giant leap for healthcare.

Keywords: biological signals; physiological signals; extreme environments; extraterrestrial devices; healthcare; health monitoring; measurement devices; stress

2 Introduction

Now that mankind has walked the moon, and the ISS is constantly occupied, humans are dreaming of going further. Mars seems like a viable option, as it is close, Earth-like, and recently discovered to have liquid water on its surface (NASA, 2015). This would make it the ideal place to start a colony. There are many companies that are working on starting this colony of which NASA, SpaceX and MarsOne are some examples.

However, there are quite some problems that one could encounter if humans were to live on Mars. First of all, the environment is very much different from that on Earth. The need to adapt to the new environment, together with the tasks, lack of communication, or boredom, could lead to physical changes and high levels of stress (Manzey, 2004). Due to the physical and mental changes that can occur, there can be negative consequences on the wellbeing and functioning of the crew. To prevent this, it is necessary to monitor both physical and mental health to guarantee the safety of the astronauts. This proposed research will develop a system that can collect data and monitor the mental and physical health status of an individual.

3 General problem analysis and research topics

As mankind's exploration in outer space moves more and more towards unchartered waters, there is a huge opportunity in improving the health monitoring system for those that will enter the dangerous and new environments.

The main danger for mental health in space is stress, caused by multiple factors. High stress levels can result in malfunctioning of a member or crew. This could be dangerous in a Mars setting, where communication with earth is slow, and the crew is very isolated. To make sure that the amount of stress will not reach dangerous levels, a system could be used that monitors different variables and stressors to analyse the stress levels of an astronaut.

In order to monitor health, a system has to be created. It has been noted that there are already many wearable monitoring devices, but there is no one single combined device that measures all the necessary variables, and draws conclusions based on the collected data . This monitoring system would be highly useful, because extreme conditions could possibly trigger various symptoms that may be a risk to human health, including stress exposure.

Overall, the two topics mentioned aim at finding solutions for and improving existing health technology in space. This aim is more specifically designated for the Mars Space Mission, but can also be used in other extreme situations, once the system is created. The hypothesis is that it will improve the quality of life and sense of security, in terms of health resources, for astronauts and future space colonists, and possibly humans in extreme conditions.

4 Subtopic 1: Stress in space

4.1 Applicants

Gloria Carta and Chaja Hudepol

4.2 Introduction

Stress amongst astronauts can cause a lot of danger, as it can influence their health and performance (Geuna et al., 1995). Stress can be divided into good and bad stress, with good stress defined as a level of stress increasing productivity, and bad stress defined as a level of stress so high that it becomes a health hazard to the individual. Good stress is thus related to acute stress, while bad stress is to chronic stress (Cohen et al., 1995) (Marketon & Glaser, 2008) (Buchanan, 2000)

In this research we aim at defining the individual tipping point between good and bad stress, in order to calibrate a health monitoring system that can monitor the stress levels that a person experiences, using physiological signals, behavioural signals and perceived stress levels, and linking those to the stress inducer.

4.3 State of the art

4.3.1 Stress and performance

According to research, stress in an individual has a direct relationship with the performance level one can carry out. This relationship can be represented by an inverse U shaped diagram. As level of stress increases, the effect on performance increases positively until a tipping point is reached, where stress level is too high and affects performance negatively

(Staal, 2004). This is shown in Figure 1.

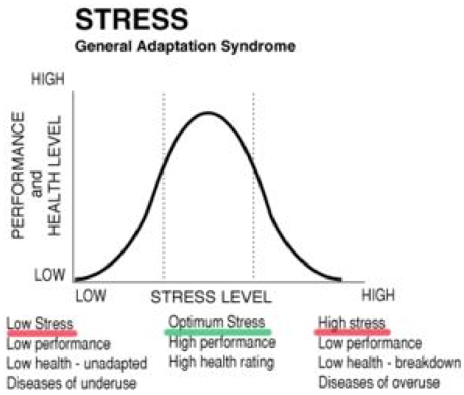

Figure 1: Stress versus performance (*graph graph*, n.d.)

Too little or too much stimulation will have a negative effect on performance. However a moderate amount of arousal will maximise performance (Staal, 2004) and can also increase group bonding (Taylor, 2006). The location of this maximum depends on the perceived level of stress of an individual, and it is a personal measurement. In this research we hypothesise that the location of this optimum does not change with changes of the environment (Staal, 2004).

4.3.2 Stress signals

Stress can be measured using physical signals. There are two types of signals: physiological signals, which are subconsciously given by someone's body and behavioural signals which are semi-conscious behaviours that can be related to stress. A further signal is perceived stress level, a direct measure which gives information about how consciously stressed a person feels (Buchanan, 2000) (ten Klooster, 2015). The interplay between these three factors has not yet been used to investigate the stress levels of an individual.

During our preliminary literature research, it was concluded that heart rate, skin conductance and blood pressure are the best indicators of stress, both in terms of giving the right indication and ease of detection (Wijsman, 2014) (appendix A). The interplay between these factors and stress can be found in Figure 2. Based on the findings, a proposed model for how the monitoring system could function was made, this can be found in appendix C. When using these variables there are some factors to take into account. Heart rate can change as a response to other factors (ex. Excitement, physical activity, etc). Both systolic and diastolic pressure are good indicators. Lastly, sweat measured by skin conductance has very specific chemical properties per type of causation, which makes it a good indicator as well (Wijsman, 2014).

	Effect of stress on variable	Long term or short term response	Gender consideration
Heart rate	Increases	immediate	Better indicator for females
Blood pressure	Increases	long term (20 minutes)	Better indicator for males
Skin conductance	Increases	immediate	Non defined

Figure 2: The interplay between the factors mentioned and stress

The most significant behavioural measure related to stress is speech. When a person is stressed, less nasal phones are used, and people speak more quickly. However, voice is difficult to relate to only stress, but could function as an addition to the physiological measures (Godin & Hansen, 2011). There are other behavioural signals, such as aggression or change in sleep pattern, but more in-depth literature research is needed to define them further (Buchanan, 2000).

A very important aspect of stress is not just the stress level itself, but also how much a person perceives him or herself as being stressed. According to Peter ten Klooster [1], questionnaires can be very useful methods of measuring health systems, as well as stress. A short questionnaire measuring stress will be included in our stress detecting system, to see how much the subjects perceive themselves to be stressed. (ten Klooster, 2015)

4.3.3 Potential stressors

Research about coping with stress has always been done using stressors that are familiar in a terrestrial environment. When in space or an extreme environment, there is a number of possible stressors that may affect an individual. These have been defined as physical, habitability, psychological, and interpersonal stressors. Physical and habitability stressors include aspects such as acceleration, microgravity and vibrations, and ambient

[1] Peter ten Klooster did a PhD project on the assessment of health status by self-report questionnaires. He received his PhD for his thesis entitled "Interpreting patient-reported outcomes in rheumatology." His research interests include (modern) psychometrics, health assessment, and "the patient perspective" specifically with respect to rheumatic diseases.

noise respectively. The more individual based stressors are the psychological and the interpersonal stressors. The psychological stressors include environment, such as isolation, workload, sleep disturbances, and a sense of danger and confinement. The interpersonal stressors are less specific but crucial in a crew setting, such as leadership issues, crew size, crew ground communication, and personal conflicts (Geuna et al., 1995). Furthermore, the time period in which a crew is in space seems to have an effect on psychosocial effects of astronauts and the crew they are in (Manzey, 2004).

Even though the habitability stressors are different, the physical, psychological, and interpersonal stressors are applicable to both extreme terrestrial environments and extraterrestrial environments. Therefore we hypothesise that the causes of stress in these two settings are very similar. This allows us to broaden the scope of this research to not only focus on astronauts, but to apply it to humans in all extreme conditions (Sandal et al., 2007) (Harrison et al., 1991).

4.4 Problem analysis

There has been extensive research on physiological responses to stressors on Earth (See Appendix B). However, the interplay between physiological signals, behavioural signals and perceived stress level has not yet been focused on. With this research we aim at quantifying the relation between the different signals in order to create a monitoring system which will assess stress levels, and relate this level to the stressors that one has been exposed to. This will be researched in simulated extreme conditions, including aspects such as isolation and confined spaces. To calibrate this system, the theory of optimum stress level will be used to define the tipping area between good and bad stress levels.

So the focus of our research will be: "Selecting the most critical physical and behavioural signals for an individual in an extreme environment, assessing the selected variables' relations to each other and to environment-specific stressors, in order to define the tipping point between a good and bad level of stress and find the causal stressors.".

4.5 Research

4.5.1 Choice of subjects

In order to investigate the stress tipping point of the individual astronauts, research has to be done on these individuals themselves or possible substitutes. The subjects chosen should have already been selected for a mission in extreme environments. Individuals selected for space missions may not be available for research, which leads to the necessity of selecting a broader scope of possible subjects, namely anyone who is selected for missions in extreme environments.

4.5.2 Literature research

In order to come to a fitting experimental research, the researcher first has to conduct further literature research.

The topics to be investigated further are: behavioural signals of stress, specific stressors applicable to the research, performance tasks appropriate for missions in extreme environments, and lastly methods to assess perceived stress level. After having completed the literature study, the researcher should be able to finalise the research using the previously mentioned elements.

4.5.3 Experimental techniques and measurements

Our hypothesis is that there is a tipping point between good and bad stress levels and that this tipping point can be a topic of research and can be computed.

Firstly, the subjects' individual variables baseline under standard conditions will be determined. Possible variables have been suggested earlier in the proposal, the most appropriate will have been selected during the literature research. Data will be gathered with appropriate techniques for the different variables (physiological as well as behavioural) for an extended period of time. Consequently, the variables should be individually assessed when the subjects are put under tailored stressors. Stressors selected should be relatable to the ones found in restricted, extreme environments. The relation between the stressor, stress level and the duration in which a person is put under stress will be investigated and recorded. Perceived stress level will be investigated to determine at what point the maximum level of stress has been reached, and what the different variables look like at that point. The measurement of the stress variables before, during, and possibly after the subjects have been exposed to the stressor should be repeated multiple times over a longer period of time. This resembles the technique used in studies on stress and stress variables(Boyle et al., 2016) (Schommer et al., 2003). As a further indication to confirm the levels of stress found, cortisol levels could be investigated. However, this is dependent on the researcher. The same measuring procedure should be then repeated, adding suitable performance tests while the subject is under stress.

A quantitative relation will be drawn from the interplay between the variables, the stressors, the perceived stress level and performance. Based on this, a tipping point can be defined. The whole research procedure should be reviewed and approved by an ethical committee before getting into practice.

The research is based on the assumption that the tipping point will not significantly change in an extreme environment and over time. Once a tipping point has been identified, the research will be simplified for the subjects to be able to perform it on themselves in the extreme environment. If the tipping point has indeed not changed, after accounting for the physiological changes of microgravity or other environmental factors, the research will have provided a stable and reliable measuring system to assess stress levels.

A complete timeline of the research can be found in figure 3.

Time	**Action point**
8-10 months	Literature research into suggested topics
12 months	Set up research and find test subjects
12 months	Conduct research
6-8 months	Data processing and analysis, and creating a model
6 months	Writing thesis

Figure 3: Timeline of the research

4.6 Relevance

Stress is a dangerous issue in terrestrial conditions. However, in an extreme environment such as a long term space mission, it can lead to even more significantly negative outcomes (Choukèr et al., 2015). As mentioned in the state of the art, there is a number of possible stressors that may affect an individual in an extreme environment. There is not yet a system that can take into account multiple variables to monitor someone's stress level, and connect this reaction to specific stressors.

4.7 Outlook

This research will result in a system able to monitor and interpret the stress levels of an individual. When functioning fully, it could also be used in non-extreme conditions, such as health care or a general working environment. However for different target groups, different physiological signals might be applicable. Possible improvements could be made, such as taking into account more variables, thus making the system more specific, fast, reliable in its assessment, and easier to adapt to a single person or target group. Furthermore, the system could provide additional tailored suggestions on how to decrease an individual's stress level. A research for the tailoring of the device to the needs of specific target groups can be conducted, considering the environment in which it operates, age and gender.

5 Subtopic 2: Implementing wearable health technology in extraterrestrial settings

5.1 Applicants

Kwan Suppaiboonsuk and Yanick Verkerk

5.2 Introduction

A few decades from now, Mars might already be inhabited by a large colony. Like the current situation on Earth, it would be interesting to know the health condition of the planet inhabitants. The use of wearable health technology (WHT) is already becoming more common for ordinary conditions on Earth. Implementing this innovative technology in extraterrestrial settings can be very promising. However, just bringing the commonly used WHT to Mars does not go without rethinking the design and specification.

The research proposed in topic one is about determining stress levels that people experience in extreme environments, the variables that are used for this determination, and how to process them. This second research will be a follow up research that incorporates the results of the first topic. It aims at a more general health monitoring system including stress.

With this research, the aim is to find the most important variables that should be implemented in WHT for extraterrestrial settings like that of Mars. This research also aims to determine the best (combination of) methods in measuring those variables, as well as the approaches in which the data can be interpreted and presented.

5.3 State of the Art

5.3.1 Wearable technology

Wearable technologies are defined as electronic devices that are implemented into outfits and accessories. They must be useable without hindering the usual activities of the users, therefore a requirement is to be non-obtrusive. These technologies should be functional in modelling and recognizing the "context sensitivity" of the user. This means that it should be able to analyze the physical state and activity of the user, as well as his or her surroundings (See Appendix D). Currently the abilities of smart wearable systems include physiological, biochemical, and motion sensing (Lukowicz et al., 2004) (Chan et al., 2012).

It can be generalized that sensors function by translating physical quantities to electrical quantities, which is then brought to a realization. As for a measurement system, the sensor should obtain data that is processed and visualized for presentation to the user (See Appendix D).

To break it down, the first phase for a measurement system is the data sensing phase. This is when the sensor does its job. The reliability of the sensor is important. In biological measurements, data can be highly affected by movement. For a most reliable wearable measurement system, there should be least errors when the user is in motion. The second phase is the analysis of data, in which the signal obtained by the sensor is processed. The needed data is computed and noise, or unwanted data, is filtered out. The final data is stored and presented in the third phase. How the data is visualized depends on who it is presented to. This could either be directly to the user or to their doctors (See Appendix D).

5.3.2 Usage of wearable (health) devices

For body fluids such as tears, sweat, urine, and blood, wearable chemical sensors have been developed for real-time monitoring of these variables. Another variable, heart rate, is also used a lot in wearable technology, with stress as a possible measurement outcome. Additionally, emotional data can be collected via wearable devices by measuring blood volume pressure, facial muscle tension, and skin conductance which measures electro-dermal activity. All mentioned examples are just a small fraction of the possibilities of smart wearable systems (Chan et al., 2012). Not all wearable devices that are being used in everyday life on Earth were initially developed for commercial use. Many have been adapted from wearable devices that were originally made for astronauts. An example of these astronaut devices is a watch that measures ultraviolet radiation

(Plummer, n.d.).

For different variables, there are often multiple types of sensors that can be used for measurement. Each sensors may vary in size and working principle (See Appendix E).

5.3.3 Human Body in Space

In microgravity astronauts no longer need the full strength of the skeletal and muscular systems for support of an upright posture. When the muscles and bones are not used, they decay or ‘’decondition”. The bones lose calcium and become weaker and muscles decay. This results in a decrease of bone stiffness and strength. The atrophy of muscles increases fatigue and abnormal reflex patterns. In addition, blood and body fluids are no longer pulled down and will redistribute and shift to the upper part of the body (See Appendix E).

5.3.4 Signal analysis

Beyond the current available technology, it is also currently known that data can be analyzed and the health risks can be interpreted. Biometric data gained from the technology can be converted to meaningful values that indicate how much the user is at risk of health hazards. This information can be properly displayed, along with the model of the data obtained, to help in monitoring the user’s health (Wisloff & Gutvik, 2015).

Signals can look really complex and this makes analysing them rather difficult. To make signals easier to analyse, certain methods can be used. Filtering and/or transforming a signal will make interpretation easier. An example of this is using Fast Fourier Transform (FFT) to analyze an ECG (See Appendix F).

5.4 Problem analysis

When Mars is going to be inhabited, it is very important that the astronauts are monitored constantly. It will take a long time before Mars is inhabited by a lot of people and the resources for health will thus be limited. Issues concerning health should therefore be addressed relatively quickly. Monitoring health is a very broad topic and with the current hype in smart health technology, the decision has been made to focus on monitoring health in an extraterrestrial setting with smart health technology with an interest in wearable health technology.

Nowadays there are many wearable health technologies available for monitoring physical health of humans on Earth. These technologies mostly monitor values such as heart rate, steps taken, calories burnt, blood pressure, and many more. However, most technologies being used currently measure only one or a few variables related to health instead of having one wearable device that combines a lot of variables.

Designing such a technology requires different issues to be solved. The most important question to be answered is what variables should be measured by the device. The focus of this proposal is on the variables that are relevant to monitor health in extraterrestrial settings. This led to the following final research question:

What variables related to physiological and physical changes should be measured to create the most all-round health monitoring device, as a wearable, for an extraterrestrial environment? How can these variables be measured and how can the measured data be interpreted?

This research question has some constraints. Starting with the most easy reason that the environment of Mars is not completely understood yet. This makes it difficult to take environmental aspects into account and the testing has to take place in an artificial or different setting. Additionally it is difficult to determine what the life of the Martian will look like when the colony is built and therefore it will be a bit more difficult to determine which health issues have to prioritized over others. Finally it will probably be necessary to personalize the wearable health technology to individuals, so that they receive health information that is most relevant for them. However this research does not focus on individualizing a monitoring device, the framework that will result from this proposed research will be a good start for that.

5.5 Research

The plan for the research is for the researcher to perform a lot of literature research and some experimental research. The end product will be a theoretical framework for the system and design of a wearable health monitoring device. Figure 5 gives an overview of the assumed time that is necessary for each step in this research.

The first step is a general literature research to define important health issues, along with the human physiological and physical variables related to them. The variables are those which should be measured in order to prevent the onset of those health issues or to determine them in an early stage. In addition, the researcher will research the environment of

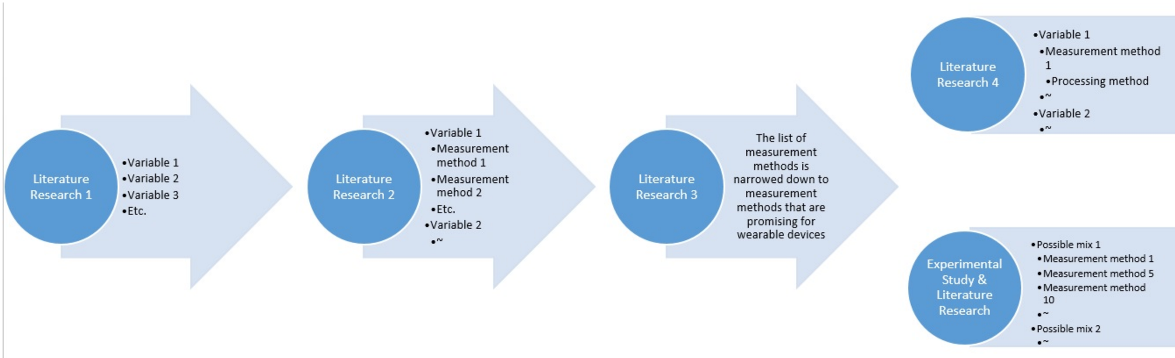

Figure 4: Visualization of the research process

Mars and identify the environmental variables that are relevant to human health, and thus should be measured. Vice versa, researchers will also research the human health variables that may be affected by the (change in) environment.

As soon as a list of important measurement variables has been made, the research can proceed to the next step. This next step is a second literature research on the various possible methods of measurement for each variable. The methods of measurement will have to be those which are possible for implementation for a wearable device. Therefore, eventually the methods of measurements will have to be narrowed down. Literature research should also be done on the current health monitoring devices used in space. To create an all-round health monitoring device for outerspace, it should be taken into account what is already being used in the field. After this in-depth literature research, there are two separate steps that have to be taken.

The first is to research how the output data for each variable can be interpreted and visualized. The second is an experimental research to test the compatibility of each measurement method in one device. During this experimental research, tests will be done on human subjects, therefore, the researcher will have to take into account the ethics of technology. Within this session, the researcher will have to contact and get their experiment approved by the ethical committee of the University.

The final step is to write a thesis on the findings obtained from the research. This thesis is the theoretical framework for a future wearable health monitoring device for extraterrestrial settings, more specifically, Mars.

Timeline for 4 years	
Amount of Time	**What should be done**
8-10 months	Literature research on general variables
6-8 months	Literature research on measurement methods for each variables
6-8 months	Literature research on most promising methods for WHT
12 months	Experimental research on compatibility of methods
6 months	Research on data processing
6 months	Writing of thesis

Figure 5: TImeline assumption of the research

5.6 Outlook

The research can be considered completed when a theoretical framework for a wearable health monitoring device has been achieved . This theoretical framework will address the variables that relate to health monitoring in extraterrestrial settings, as well as methods to monitor those variables.

Not only is this research of value for extraterrestrial settings, it also adds to the already existing research on wearable health technology with an implementation on earth. Creating an all-round wearable device to monitor as much health aspects as possible can be applied anywhere. Changes in variables and the involvement of the environment are factors that should again be looked into in this case. However, most details are relevant for both a Martian and Earth setting.

This research also provides a platform of foundation for future research. A possibility for a follow up research can be on how to combine different measurement methods in an efficient way to put as much variables in as few devices as possible. Further research can be done on how to make a new sensor, if a certain variable cannot be measured yet with a wearable or small device. Extensive research can also be done on the storage of data for the measurement device. If enough research is conducted, this could result in a wearable health device that the Martians can wear in order to monitor various crucial health aspects.

6 Integration of subtopics

The ultimate research goal is to create a framework of how a (wearable) health monitoring system works. Combining the two researches will result in a complete understanding of what variables should be used for designing a wearable health device for usage in extraterrestrial settings. These variables will contain the ones that are used to assess stress, but will also cover the most important variables for measuring general health. The addition of further variables, defined by the second research topic, will be used to globalise the use of the wearable device, which will result in the device being able to assess a larger number of health conditions, and is not limited to stress.

This research will deliver not only an understanding of the variables, but also knowledge on how they can be measured in different ways and what their relation is. It creates a framework of what a wearable health technology should look like. This information can be used to design the most efficient wearable health device, that looks at both physical and mental health.

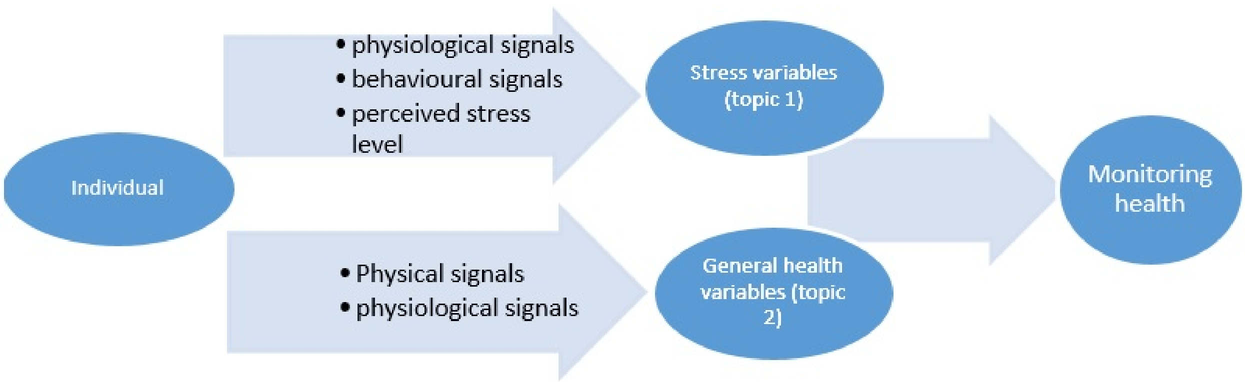

Figure 6: Visualization of the research as a whole

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7 Appendix

A Measuring stress

Stress can be measured in roughly three different ways; using physiological signals, measuring perceived stress, and looking at behavioural signals.

A.1 Physical measures

Peter ten Klooster [2] informed us that stress occurs when the demand of a situation is too high for the level of coping the individual can perform. Stress is a very good example of a health problem that has multiple dimensions,both physiological and mental. The body undergoes physiological changes responding to a stressful situation, which also reflects in the mental state and behaviour of the person. Therefore there are a number of different ways to assess stress levels, from looking at the physiological changes via EGG, EMG or more immunological measures, etc. A very big problem of trying to measure the biological response is that the methods are intrusive, the equipment is expensive and hard to transport, and people would actually have to be put under a stressful condition which may not always be ethically possible.

The physical measures that can be used to monitor stress are first of all the hormone levels of Epinephrine and Cortisol which are only expressed internally. these hormones do however result in a set of external responses; which are elevated heart rate and blood pressure, respiration rate, skin conductance, muscle activation and skin temperature (Wijsman, 2014) (Schommer et al., 2003) (Nater et al., 2005).

Measuring hormone levels is very difficult, as these hormones have to be detected in blood, saliva, or urine. For this detection a set of specialised equipment is needed. Secondly the hormone expression in saliva and urine is only present after about 20 minutes after the stressor occurred, so there is a large delay in the detection. Lastly the hormone expression can also be elevated due to other factors, such as hunger or excitement. These factors make hormones less practical and reliable as a stress indicator (Wijsman, 2014) (Boyle et al., 2016).

The external responses are easier to measure, as only a detector on the skin is needed. Heart rate is very easy to detect, and the heart

[2] Peter ten Klooster did a PhD project on the assessment of health status by self-report questionnaires. He received his PhD for his thesis entitled "Interpreting patient-reported outcomes in rheumatology." His research interests include (modern) psychometrics, health assessment, and "the patient perspective" specifically with respect to rheumatic diseases

rate is elevated almost immediately after a stressful situation has been encountered. However heart rate can also change as a response to other factors, such as excitement or physical activity (Healey et al., 2005).

As heart rate, blood pressure is also quite easy to measure, and the blood pressure changes very shortly after the occurrence of the stressor. Both systolic and diastolic blood pressure are good indicators of stress, however the blood pressure can stay elevated long after the stressor has disappeared (Schommer et al., 2003).

Respiration rate is very difficult to link to stress, as it can differ due to a large variety of factors. The same applies for muscle activation and skin temperature. However skin conductance is a very clear indicator of stress. Skin conductance can be measured through the level of conductance, and the number of responses. Both seem to be a good indicator of stress. With skin conductance it is easier to ignore sweat caused by other factors, as roughly three types of sweat can be distinguished; eccrine, apocrine, and apoeccrine, of which eccrine indicates emotional responses (Wijsman, 2014) (Healey et al., 2005).

We concluded that heart rate, skin conductance and blood pressure are the best indicators of stress.

Signals	How to measure	Why to measure
Respiration		problems -affected by speaking and physical activity as well -not very consistent results
Heart rate	heart rate monitors	indicates stress level good correlation between stress and variability
Cortisol level	blood and saliva (delayed reaction)	-gives an indication of stress level -direct measure -less invasive than measuring adrenaline problems: patterns changes through the day regardless of stress level and very obtrusive and difficult to measure
skin conductance	look at both level and number of skin conductance response	very clearly relatable to stress and very simple to measure
blood pressure	a bit invasive	good long term stress indicator

Figure 7: Table of physiological measures

B What are the effects of stress

Being an astronaut is a very intensive job, that demands the astronaut to be physically and mentally fit at all times. Having a high level of stress can affect both the physical and mental state of an astronaut, which could make them incapable of functioning optimally.

B.1 Mental

The multiple stressors in space can lead to the development of mental illnesses, such as depression, anxiety and aggression. If one of those defects were to develop during a Mars space mission this could result in malfunctioning of the team and thus possible failure of the mission. (Geuna et al., 1995)

B.2 Physiological

Stressors can lead to an effect on the biological system of the person, which can provide physiological changes that could potentially be detected, so that the negative consequences of stress can be monitored and prevented. Example physiological changes due to the presence of stressors can be a change in blood pressure, respiration rate and heart rate. A prolonged exposure to stressors, and therefore stress, could lead to physiological changes that may then cause further psychological issues, such as depression. Research also shows that the astronaut in space undergoes some physiological changes during adaptation phase which should be taken into account when looking at the physiological changes caused by stressors, as these changes stress responses can fade once the astronaut is adjusted to the new environment. (Manzey, 2004) (Geuna et al., 1995)

C Qualitative model

As seen in the previous sections, there is a correlation between heart rate, skin conductance, blood pressure and stress level. This information lead to the following qualitative proposed model for the functioning of the system: Heart rate and skin conductance immediately react to stressors, so they are measured and checked constantly. If they are significantly increasing, the blood pressure will be checked. In the case that after a period of time longer than 20 minutes this has also increased, behavioural signals and perceived stress level will be checked. If at any point in the process, the variables do not suggest a significant state of stress in the individual, the system will go back to monitoring the heart rate and skin conductance. This process is visualised in Figure 3 (Wijsman, 2014).

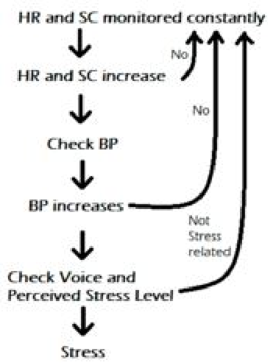

Figure 8: Proposed qualitative model of a monitoring system. HR = heart rate, SC = skind conductance, BP = blood pressure.

D Measurement systems and sensor principles

This paper is a summary of the reading we did from the book Biomedical Sensors and Instruments for a part of our project elective (Togawa et al., 2011). From this elective, we learned the characteristics of a measurement system and about examples of certain devices. From the physiological variables we might like an aerospace health monitoring device to measure, we then read about the sensors that could measure some of those general quantities: motion, force, pressure, temperature, evaporation, humidity, and bioelectric signals. The principles of those sensors are briefly studied.

This summary starts with the fundamental concepts of signals and systems. Afterwards a few parameters are discussed with respect to the basic principles of their characteristics and what the principles are of measuring them. The parameters discussed have been chosen, since they can be of use for creating an all-round health monitoring device.

D.1 Fundamental Concepts of Signals and Systems

This chapter discussed the basic concepts of signals and systems. The focus of the system is mainly on measurement systems. Measurement is defined as a procedure done by an observer in which a quantity of an object is determined. The quantity is a value that characterizes the object by identifying which state the object is in or what property it has. For biomedical measurements, the quantities are usually dependent on time.

A signal is part of what is obtained in a measurement procedure. It is the component that actually contains the information for the object. To find the wanted quantity, which depends solely on the observer, the signal is analyzed. Through analysis, noise (or unwanted component) may be filtered out.

Overall, a measurement system is a 'box' that receives an input and delivers an output, which is a wanted quantity. In the 'box', a sensor translates physical quantities into electrical signals, which is analyzed, and presented as visualized data, given as output.

D.2 Motion and Force Measurement

In motion measurements, coordinates are used as units to describe the movement. There are many methods in which motion can be measured. One of the more basic tools that are used to capture movement is the video camera. Even though it may sound simple, the process for obtaining and analyzing physical biological data is complicated.

A simple and accurate tool for motion measurement is a goniometer. This sensor can be attached to the human joint, all the while without disturbing the user's movements. The difference between the goniometer and a video camera is that the camera is measuring with a fixed coordinate system, while that of a goniometer is constantly moving.

The main principles behind motion sensors is the measurement of displacement, velocity, acceleration, and if applicable, rotation. There are also multiple ways in which these measurements can be made. One is via contact sensors, such as potentiometers, photoencoders, and magnetic sensors. Although, if forces are small, the friction from the potentiometers may result in an unreliable measurement.

As for force measurement, when done on a body in motion, inertial forces have to be taken into account. Force can be measured from acceleration measurements, therefore it can be measured with multiple accelerometers.

Apart from accelerometers, direct force measurements can be made through muscle contractions. This is done by connecting one end of the muscle to a force sensor, while the other end is attached to a fixed point.

For ground force measurements, or the amount of force that a person is exerting on the ground, especially when walking (which can be useful for gait analysis), force plates can be used. Currently force shoes, which are shoes enforced with force plates, are used in space.

Because the human body is not rigid surfaces, it is important that the reference points for the coordinate systems are standardized.

D.3 Pressure measurements

Pressure is defined as the force exerted per unit area. Physiological pressures are normally measured and expressed relative to the atmospheric pressure. Pressure is measured in relation to the atmosphere and therefore it is normally unnecessary to specify the absolute atmospheric pressure. However, when the pressure in the body is measured by an indwelling sensor that measures absolute pressure, the physiological pressure has to be determined by substituting atmospheric pressure from the obtained absolute pressure.

Pressure in the cardiovascular system can be measured in different ways. Arterial blood pressure is routinely measured is in most patients, and is accepted as index of circulatory condition. The quantities measured are systolic and diastolic pressure. In the systolic phase, the aortic valve of the heart is open, and the arterial pressure reflect the mechanical activity of the heart ventricle. In diastolic phase, the aorta is closed, and then the time course of the arterial pressure reflects the movement of the blood from the aorta to the peripheral vascular system. The arterial pulse pressure, which is defined as the difference between systolic and diastolic pressures, is an important quantity relating to the characteristics of the heart and the arterial system.

Pulmonary wedge pressure is also commonly measured. It is the pressure observed when the catheter introduced into the pulmonary artery is wedged at a branch of the pulmonary artery. The pulmonary wedge is in between the true capillary pressure and the pressure in the left atrium, and it is used as an estimation of left atrial pressure.

Central venous pressure is the pressure in the central vein close to the right atrium, and is the resulting pressure developed by venous elasticity and intrapleural pressure. The absolute pressure in the intrapleural space is normally between below 1 kPa. Intrapleural pressure is normally almost equal to atmospheric pressure, and the central venous pressure can be an index of the blood volume in the venous system and elasticity of the veins.

Atmospheric pressure is applied uniformly to the human body. Thus the sensor which measures pressure relative to the atmosphere is not affected by a change in the atmospheric pressure. However, when a sensor which measures absolute pressure is used, variations in atmospheric pressure should be considered.

Due to gravitational force, the pressure at a specific site may change when there is a change in posture. To avoid any ambiguity, in this regard, it is postulated that most clinical pressure measurements are performed with the patient in a well-defined posture. However, even if the posture is the same, some ambiguity still remains due to the level at which the sensor is placed. The reference point at which the pressure is zero is used in determining the appropriate level to place the sensor. There is a site in the cardiovascular system where the pressure remains constant regardless of posture. It has been shown that right atrial pressure is the most stable pressure in relation to posture changes. This is important for measurements while someone is moving.

D.4 Temperature sensors

Temperature is measured at many different sites of the body for clinical diagnosis and patient monitoring. In humans the temperature of the central part of the body is stabilized by a physiological thermoregulatory function, and the deep tissue temperature at the central part of the body is called the called the core temperature or deep body temperature. When talking about body temperature, the core temperature is most often used as an indication even though the body is not uniform but can vary from site to site.

The range of a skin temperature measuring device can 0-50 degrees celsius due to different circumstances that the body can be in. Although, for some cases such a device needs a smaller range to be more precise. The resolution, absolute accuracy, and response time of the thermometer required for skin temperature vary according to the purpose.

DIfferent types of temperature sensors are available of which thermistors are one. A thermistor is a semiconductor-resistive temperature sensor made by sintered of metals such as manganese, cobalt, nickel, iron or copper. The resistance of a thermistor has a negative temperature coefficient, typically about -0.04/K. It is suitable for use in physiological temperature measurements, where relatively high resolution in required in a narrow temperature range.

Another type of sensor is a thermocouple, which is a thermoelectric sensor. A circuit composed of two dissimilar metals A and B provides an electromotive force that depends on the temperature difference between two junctions. It is known as the Zeebeck effect.

A thermoresistive element in another sensor type, which is made from a pure metal. It has the advantages that is has a constant temperature coefficient and linear output can be obtained in a wide temperature range. These advantages are less significant for biomedical applications, where other specifications are prefered. For this type of sensor platinum is the most common material to use.

The resonant frequency of a quartz resonator has a temperature coefficient and can be used as a temperature sensor. The temperature coefficient of a typical crystal temperature sensor ranges between 10 and 100 100ppm/K. The crystal temperature sensor has an almost uniform temperature coefficient is a wide temperature range.

D.5 Measuring Evaporation and Humidity

Something besides temperature, but which is related in some ways, is evaporation. Water loss via the skin can be measured by devices. This loss is mediated via two physical processes, diffusion through the epidermis and low level sweat secretion via the sweat glands.

Measuring humidity of air can be measured by an electrolytic water vapor analyzer. The measurement cell in electrolytic water vapor analyzer is usually a cylindrical tube through which a continuous carrier gas flow is conducted. Inside the tube two helically winded platinum wires are arranged and supplied from a direct current source. A thin layer of phosphor pentoxide is deposited between the spirals. Water vapor is absorbed by phosphorus pentoxide. A small electrical current passes between the platinum wires. The magnitude of this current is related to the water content.

Another way of measuring humidity is via an infrared water vapor analyzer. It is based on the infrared absorption properties of water vapor at 2.37 um band. The measurement cell is usually divided into two tubes, one containing the gas under study study and the other a reference sample. With a humid gas in one tube and the dry reference gas the detector records an imbalance signal and can in this way measure the humidity of the test sample.

Evaporation water loss from the skin is estimated by passing a continuous flow of gas with a known water content and a known flow rate through the measurement chamber. The water content of the gas can be measured by an electrolytic water vapor analyzer.

The human body is under undisturbed conditions surrounded by a water vapor boundary layer. If the vapor pressure and temperature distribution are known, the evaporation water loss and convective heat loss from the skin surface can be calculated.

D.6 Bioelectric Measurements

In hospitals heart rhythm is a very common measurement being made. Electrodes are used for this measurement since it uses electrical signals and they can also be used to measure other signals, like an EMG. Most electrical events in the human body have amplitudes below 1V. The resting potential of a cell may be as high as 0.05-0.1V, whereas voltages recorded from the skull related to the activity of the central nervous system may be as low as a few microvolts. This shows that measuring these signals should be really precise. Table 1 shows some common

Electrophysiological Parameter	Signal Range (mV)
Electrocardiography (ECG)	0.5-4.0
Electroencephalography (EEG)	0.001-0.1
Electrocorticography	0.1-5.0
Electrogastrography	0.1-5.0
Electromyography (EMG)	-
Electrooculography (EOG)	0.005-0.2
Electroretinography (ERG)	0.01-0.6
Nerve potentials	0.01-3.0

Table 1: Electrophysiological variables and their magnitude range

Figure 9:

physiological signals and the range in output they give.

Bioelectrodes are devices that transform biochemical and physiological signals into electrical currents or generate such signals from electrical currents. Measurement devices make use of the fact that electrolytes in biological solutions and body tissue contain charged particles, ions. The electrode's function is to transfer charge between ionic solutions and metallic conductors. This charge will turn into a signal which can be interpreted.

As a result of the charge distribution close to the electrode surface, the electrode itself acquires a potential. It is not possible to measure the potential of a single electrode with respect to a solution. Therefore, electrode potentials are always measured in relation to a standard electrode. Such an electrode is the standard hydrogen electrode (SHE).

For ECG measurements, a Silver-Silver Chloride electrode can be used. This electrode type consists of a metal silver substrate coated with AgCl. When such an electrode comes into direct contact with an electrolyte containing chloride ions, an exchange takes place between the electrodes. Another type of electrode that is used for ECGs is a stainless steel one. This type of electrode polarized far more than silver-silver chloride.

The invention of the field effect transistor made it possible to design amplifiers with a very high input impedance. With such an amplifier as

input stage, it is possible to design electrodes that can be used directly on the skin without paste or low-ohmic paths between the electrode and the tissue. Such electrodes are called dry or capacitive electrodes.
It works with a metal plate that is placed against the stratum corneum, which is the outer layer of the skin with dead cells, and a metal electrolyte interface is created. The impedance is mainly resistive because of the stratum corneum that works with as an isolating medium. The deeper parts of the skin have higher conductivities. Therefore, there is a capacitor with the metal plate, the dermis as conducting plates, and the stratum corneum as the dielectric. A disadvantage of dry electrodes is that the high impedance amplifier is very sensitive to electric fields around the electrode.

The use of a pasteless electrode has been suggested for long-term applications such as space missions. High-impedance electrodes have to be used in connection with these types of electrodes because of the high skin-to electrode impedance.

Next to ECG signals, EMG signals can also be measured by electrodes. Two electrodes are used to record the electromyographic (EMG) signal. Surface electrodes are used on the surface of a muscle or skin above the muscle under study. Needle or wire electrodes are inserted into the muscle for signal extraction. Electrodes for EMG can be used singularly or in pairs.

E Human Body Mechanics and Properties

As part of our project elective, we have followed a few lectures from the course Biomechanics. In addition we followed parts of an online MIT course ''Aerospace Biomedical and Life Support Engineering'' about the human body in space. This paper is a summary of the topics covered in the lectures and papers. In the sections below, the definition of biomechanics will be given, along with the general characteristics of the biological materials, with more focus on bone.

E.1 Biomechanics

Biomechanics is defined as "science that examines forces acting within a biological structure and effects produced by such forces." When compared to regular mechanics, biomechanics is much more complex due to the highly nonlinear nature.

When discussing biomechanics, movement anatomy is considered. Movement anatomy refers to the parts of the body that are involved in the motions of the (human) body. These are the musculoskeletal system (bones, joints, ligaments, muscles), the circulatory system (heart, arteries, veins), the sensors of the body, and the central nervous system.

E.2 Biological Materials

To be able to understand (human) biomechanics better, it is best to understand the biological materials that make up the components of the movement anatomy.

The basic materials specific to the biomechanics of the (human) body are fibers, substance (such as proteins, calcium, etc.), and fluids. Fibers could either be collagen fibers or elastic fibers. Collagen fibers generally have higher stiffness, while elastic fibers have lower stiffness. In addition, fibers also have high tensile strength. For substance, hydroxyapatite (or calcium phosphate) is found in bones, while proteoglycans are found in cartilage. The calcium substance has generally high compressive strength. As for fluids, an example is how there is water in cartilage.

Biological materials are unlike regular materials. Even though there may be overlapping and similar functions, there are certain characteristics that highlights biological materials. The first is what makes it so complex and intriguing; that is how it is nonlinear and nonhomogenous. Biological materials are anisotropic, meaning that for different directions/planes, there may be different properties.

Because biological materials are living materials, there is constant adaptation. These adaptations occur in the process of damage repair, aging, and in response to load. This adaptation is also why biological materials, along with biomechanics, have a nonlinear and inhomogeneous property.

E.3 Viscoelastic Behavior

Another important property pertaining to biological materials is viscoelasticity. Visco-elasticity is the combined property of viscosity and elasticity. This means that stress, when not applied past the limit, causes temporary deformation. Viscoelastic behavior is time dependent and nonlinear.

Hysteresis is a phenomenon that provides a good example of the viscoelastic behavior of biological materials. An example of hysteresis is when one sits down on a chair, one's leg seems to 'flatten'. In hysteresis, loading and unloading have different stress-strain curve. The unloading curve is always below the loading curve, due to the more amount of work needed to be put in when loading.

Viscoelasticity also causes materials to have the property of velocity dependency. This means that the stiffness of the material depends on the velocity of the load. An example is when putting a needle in fast, muscles are stiffer and doesn't shift. The faster the needle is put in, the stiffer the muscle. Bone is a biological material that is highly viscoelastic. This is useful, because accidents often happen at high velocity. And at higher velocity, bone is also stronger.

E.4 Bone

The functions of bone are to support, protect, enable movement, and act as a calcium reservoir. Long bones protect the red bone marrow and produces red blood cells.

On a molecular level, bones are made up of collagen fiber connected with hydroxyapatite crystals, which are stiff and brittle. There are many different types of bones though, each with different molecular structures. In woven bones, the fibers and crystals are in different direction. This type of bone is seen after a bone fracture, as well as in animals that grow really fast. This bone can become replaced by lamellar bones.

Lamellar bones have a different orientation of materials. The fiber and crystal are structured in the same direction. Together, lamellar bones and woven bones make up the structure for the plexiform bone. The plexiform bone is layers of lamellar bones coated with woven bones.

As for older bones, often known as osteonal bone, it is lamellar bones structured in tubes. On a macroscopic level, there are cortical and cancellous bones. Cortical bones are dense and therefore are often found on the outer level; while cancellous bones are soft and spongy and found on the inside layers.

These bones adapt and transforms over time. They develop. The development process of bone starts shortly after conception, when a cartilage starts to calcify in the middle and periosteum (a connective tissue covering bones) starts to develop. Soon after, compact bone develops and the center ossifies and eventually a canal is formed, as well as bones.

The distribution of the types of bone in a cross section, along with the bone's overall size, shape, and thickness, are important structural factors that determine the strength of the bone. The amount of body tissue in it is also important as well (Frost, n.d.).
.

As for mechanical properties of bones, bone is anisotropic just like any other biological materials. Bone stiffness has preferred directions of mechanical loading - compressive/tensile strength differs for various directions of load. Nevertheless, all loads on a bone, no matter how small or large, can cause strains and deformations. Most of the mechanical loading on bones come from the contraction of the muscles attached on them (Frost, n.d.).

The size of a strain a bone experiences depends on the total load and the strength of the bone, which differs for each bone in the body. Under the same amount of load, strong bones would experience less strain, while weak bones would experience more. The larger the load, the larger the strain. Bone can handle up to around 25,000 microstrains. If this much strain reached, the bone may fracture (Frost, n.d.).

E.4.1 Aging

Throughout one's life, the amount of load on bones changes drastically. From the time of birth to maturity, the size of the loads on bones increases over twenty times. A healthy amount of strain on the bones is between 800 and 4000 microstrain. During rapid growth spurts, steady increase of body weight and muscle strength could help with bone adaptation to the new strain. If further strength training is performed, there are even larger strains; therefore, increasing bone mass and strength (Frost, n.d.).

Even though the amount of load on the bone changes as a person ages, the properties of bone as a biological material does not change much throughout (Frost, n.d.).

E.4.2 Bone Adaptation to Weightlessness

One of the most significant changes in bones due to microgravity is in bone mineral density (BMD). There is a decrease in the density of mineral mass in the bone, meaning loss of bone mass. This results in a decrease in bone stiffness and strength. In outer space flights that lasts longer than a month, it has been discovered that significant bone mass and BMD losses are in the bones that bear body weight, such as the spine and lower limbs. After spending a large amount of time in weightlessness, the decrease in bone strength increases astronauts' fracture risk during activity, whether intra or extravehicular (Schaffner, 2001).

If a settler is to experience bone fracture on Mars, which has a gravitational force of 3.711 m/s^2, there there could be serious consequences, not only to the settler, but also to the crew. Because of limited resources, it is difficult to give proper medical reparation to the fracture. Thus, resulting in a decreased team functionality (Schaffner, 2001).

E.5 Physiological Changes due to Microgravity

Monitoring health in space is restricted. However, it is very important. Microgravity, which is a lack of gravity, can cause many changes to the body. Figure 9 illustrates the main changes to the body that occur due to removal of gravity. (Andre et al., n.d.)

In microgravity astronauts no longer need the full strength of the skeletal and muscular systems for support of an upright posture. When the muscles and bones are not used, they decay or ''decondition". The bones loses calcium and become weaker and muscles decay.

E.6 Muscles

A large part of the muscles are used as anti-gravity muscles, especially the postural and locomotion muscles. These will mostly be affected by microgravity. Spaceflight causes loss of muscle mass, force and power and increases muscle tiredness and abnormal reflex patterns. These changes

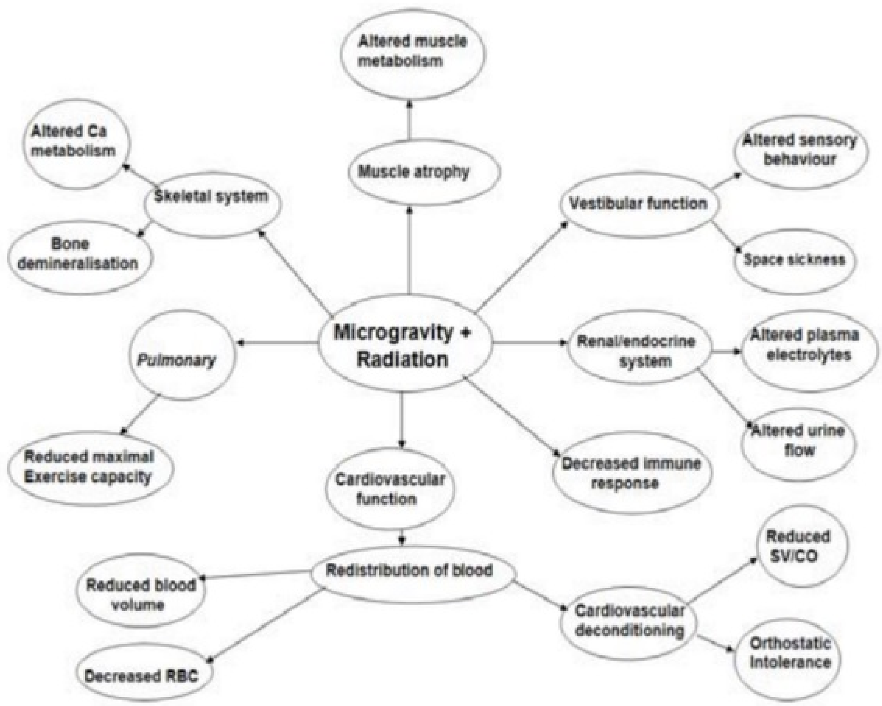

Figure 10: Chart of the main body changes due to microgravity

are due to multiple factors, among which increased muscle protein degradation and altered neuromuscular control are probably the most important. During long-term space missions, muscle decay could limit the crew's ability to work in space (Andre et al., n.d.).

The most obvious changes observed in astronauts are increased excretion of calcium and the negative calcium balance thought to be the result of bone loss. Increased urinary calcium excretion is a major contributor to the increased risk of renal stone formation during and after space flight (Andre et al., n.d.).

E.7 Effect of Radiation

Radiation exposure is most likely one of the greatest risks of human spaceflight, especially on long during space travel to nearby planets, like Mars. Astronauts are exposed to high energy charged solar and cosmic particles from deep space, ranging from protons to iron nuclei. Only little is known about the effect of these radiations on cells, tissue, and DNA. Although little is known about the effects of space travel on the reproductive physiology, reduction in testosterone levels have been reported in men (Andre et al., n.d.).

E.8 Body Fluids

When entering microgravity, blood and body fluids are no longer pulled down and will redistribute and shift to the upper part of the body. This fluid shift was quantified by using ultrasound techniques to measure tissue thickness. Understanding the dynamics of this fluid shift requires continuous monitoring of cardiac filling pressure. Central venous pressure (CVP) measurement is the only feasible way of accomplishing this. The fluid shift in the body can be simulated by putting someone in a water tank with his/her head above the water. The hydrostatic pressure on the tissue of the lower limbs results in a shift of fluids towards the upper body (Andre et al., n.d.).

A way to limit the fluid shift due to microgravity is by using thigh cuffs. This invention by the Russians compensated party for the cardiovascular changes, but does not interfere with microgravity-induced deconditioning (Andre et al., n.d.).

Astronauts have consistently returned from space with reduced red blood cell mass and plasma volume. The reduction in red blood cell mass may reflect an adaptation to the change in distribution of blood, which is gravity dependent (Andre et al., n.d.).

Something that does not change in space, is heart rate. Holter recordings during spaceflight have indicated that during normal activity heart rate was not significantly different in space compared to Earth. Mean arterial blood pressure also does not differ significantly from Earth (Andre et al., n.d.).

E.9 Monitoring Health in Space

When the health condition of astronauts needs to be measured, there are some limitations in the usage of equipment. Similar equipment as in the hospital cannot be used, since it cannot easily be brought up to space. Some restrictions are: (Andre et al., n.d.)

- Methods have to be non-invasive as possible.
- Substance for intake: have to be non-toxic to the body.
- Equipment needs to be lightweight. Bringing 1kg costs approximately 20,000 euros.

- All equipment needs to be space certified: no degassing, no risk for explosion, not inflammable, limits to power consumption etc.

F Analyzing an ECG signal

Often times, unprocessed signals are impossible to understand. They are too complex and do not implicitly display needed variables; there is a lot of noise. Therefore, it is necessary to process the signal by filtering out noise, or unwanted quantities. By doing so, a processed signal should display measurement information of a wanted quantity.

Below are examples of an unprocessed and processed signal of an electrocardiogram (ECG). In the unprocessed signal, no information can be deducted from it, due to its complexity. This signal then goes through a process of transformation with the use of a fast fourier transform and noise is filtered out. This results in the second image of the processed signal, in which information is simply displayed and two frequency peaks can be found. This shows that there are two heartbeats, a mother's and her baby's.

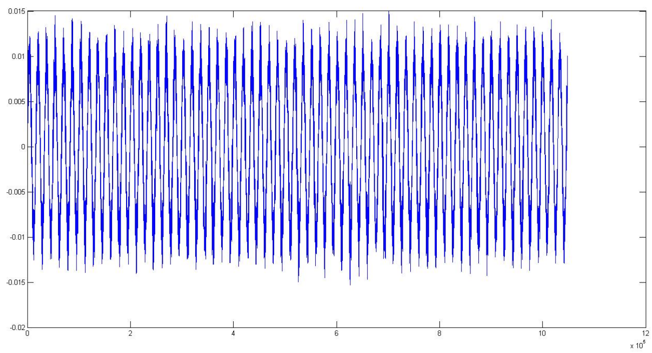

Figure 11: Example of unprocessed signal of an ECG

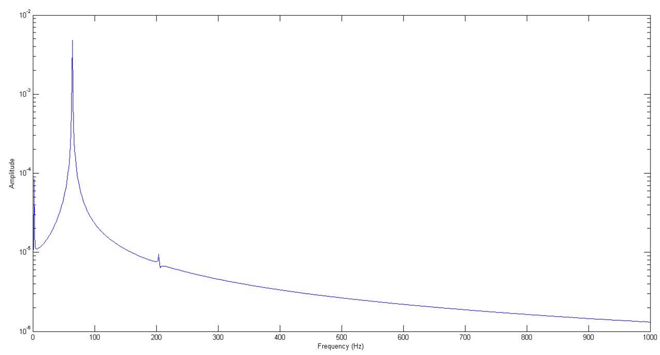

Figure 12: Example of a processed ECG signal