Readers Guide

Glossary

Throughout the report you might encounter some terms used to express a certain matter. This glossary will try to explain what is meant when these terms are used.

Auditory display	The use of sound to communicate information from a computer to the user.

Report Template

Group Number

November 6, 2014

Contents

1 Introduction

The weather forecast is a tricky thing. Everyone likes to talk about them, everyone have their own opinion about what is important and preferences on how the weather data should be presented to them. One common way of getting the weather forecast is through mobile applications. They all present the weather data in different detail, some of them show a lot of data at the same time using raw data in tables spanning a lot of pages. This could be complicated and difficult for many to read. Other weather applications show only a short set of data in a single page and using symbols and images to illustrate the most important weather conditions, such as illustrations of an umbrella when it is going to rain. These applications might oversimplify the message and the user can end up making the wrong desicions. Some of these applications will be investigated further in our analysis of the problem.

Common for all of them is that they only present the data visually and not audibly. Even on the Tv, where audio is present, the weather forecast is primarily visual in form of graphs, radar images and numbers, which a very trustable person in a nice suit interpretes for you.

Sonification which is the use of non-speech audio to convey information is also a potential way of bringing data about the weather conditions. Over the course of this report we will explore the areas of sonification and test if it is possible to use sound to create a weather forecast and still use this inborn intuition to understand the message. We will also test if it is possible to combine visual and sound to get a better understanding of the message of the forecast.

2 Pre-analysis

For this semester we have chosen the theme *Sonification*. Sonification is basically the use of non-speech audio to convey or perceptualize data **Wiki2014-2** In investigating sonification it is clear that there are more ways of sonifying data (see "Sonification Techniques" section 2.2.3), depending on what kind of data is to be converted, and how that information is to be displayed and interacted with. Sonification is used in various applications and projects (see "Examples of uses of sonification" in section 2.2.2), but sonification does face some challenges in its current state. The main problem is that it is difficult to provide adequate context for interpreting sonifications of data **Kramer1993** To see to what extend this challenge can be overcome, first one must find data to be sonified.

One area which contains different sorts of data that theoretically could be sonified is weather data. Some of these could be: temperature (degrees), sunny or cloudy (either or), wind speed (meters per second), visibility, precipitation (rain/sleet/snow/hail measured in millimeters). These data have a different range of values. For instance, temperature could be an array of degrees and overcast can be a boolean value of yes or no. This means that theoretically a lot of different sonification techniques can be applied to this kind of information. Aside from being sonifiable, weather information is not usually presented as sound (see "Weather Data" section 2.3), and could therefore possibly make for an interesting study and test of whether there could be advantages to combining non-speech audio with imagery, or possibly presenting the weather data as audio on its own, in addition to answering the question of to what extent it is possible to provide adequate context for interpreting the data.

We would like to investigate if visually presented weather data can actually be understood, and to which degree, if converted to non-speech sound using sonification. Can sonification of some of these data maybe even make the weather information more understandable or relatable? For instance, is information about wind or downpour more relatable as sound than numbers? These discussions have led us to the following Initial Problem Statement:

2.1 Initial Problem Statement

"Is it possible to successfully use sonification to convey relevant information about weather conditions as efficiently as visually represented weather conditions/data?"

2.2 Sonification

Now that we have an idea of what kind of data we want to sonify, we will first look into the basics of sonification. What it is, and how it is used so we can begin to plan sonification of weather data, and the best approach/technique for doing this.

2.2.1 What is Sonification?

Sonification is used to convey information through non-speech audio, to get a better understanding of what that is; we will explain what kind of communication methods that are most common and examples of their functions. These are visualization, auditory communication and sonification. Sonification is a subcategory of audification, and visualization is the counterpart to audification and is also the most commonly used method for displaying weather data. Both of them can supplement each other **Hermann2011**

Visualization is the communication method that we perceive through our eyes e.g. posters, TV, computer, traffic lights, chat systems, pictures, sign language, body language etc. As of now most applications that show weather data uses visualization methods, for instance, showing the temperature in numbers or a weather condition as an image **Friendly95**

Auditory communication is data that we perceive through our ears like sonification, but unlike sonification, auditory communication can use speech, which occurs in for instance, radio, TV, computers, telephones, all kinds of equipment and applications that allow you talk with people over distance. Sonification only uses non-speech audio to convey information. An example is the traffic light junctions all around Denmark. When you near a crosswalk you will hear 2 different sounds. Both sounds are the same, but they consist of different paces of rhythm. One sound (slow) indicates it is a red light, while the other (fast) indicates it is safe to walk. This helps blind people know whether to cross or not, and is an example of sonification. Sonification is a subset of auditory displays. There are several uses of sonification, and these will be described in detail below.

2.2.2 Examples of uses of sonification

Now that sonification has been defined, let us delve further into the topic and see what some of the uses for sonification could be. A good example to start out with is the use in the medical industry.

From the beginning of medical school, students are taught to use stethoscopes to listen to tissue, gases and blood pumping through veins **Barrass1999** Much of the data used for diagnosing a patient's current status is shown in numbers or graphs, but a graph can be distracting during a demanding task, and it is possible to synthesise sounds to represent this data instead. Medical students were shown to perform better in a setting where some dynamic variables about the patients status were presented with sounds rather than graphs **Barrass1999** It is also used in MRI scans to identify unhealthy regions of the brain, and listening to such data might help a doctor diagnose an illness that otherwise goes undetected **Barrass1999** There also exists multimedia programs that can make maps and text more accessible to visually impaired people.

Audiograf is an application that generates sound from part of a diagram selected with finger touch **Barrass1999** Other programs exist such as Mercator, which makes it easier for a blind person to use graphical computer interfaces, by mapping navigation and buttons into auditory cues. Some web browsers have also been enhanced in a similar way, by using sonifications to present download times, layout, hyperlinks and more **Barrass1999**

It is stated that gadgets and applications for the visually impaired using sonification have been mined thoroughly **Girvan2005** but scientific alternatives also exist. An example of this is the ULTRA (Universal Laboratory Training and Research Aid), which is a device for blind science students created by David Lunney and Robert Morrison. ULTRA can be interfaced to give speech and present readouts from laboratory equipment such as pH probes and resistance thermometers **Girvan2005**

There have also been attempts to create location devices as a replacement for guide dogs. For example, Dr. Leslie Kay's "Sonic Torch", a device using traditional sonar technology, which uses a bat-like frequency sweep to return detailed textural information **Girvan2005**

Another attempt at a location device is created by Dr. Peter Meijer and is called vOICe. This works by taking the input from a digital camera, either a mounted one or the camera from a cellphone, and using software to sweep the image with a vertical scan line. It then sonifies features in the scan by representing vertical position as pitch, horizontal position as time, and brightness by increasing or decreasing volume **Girvan2005** An interesting result that came from using this device was that a user reported experiences of seeing depth in different places throughout her house. On Dr. Meijer website `www.seeingwithsound.com`, a demo of vOICe made in Java can be found. On here the application is mentioned as "Augmented Reality for the Totally Blind". The above

Figure 1: Sonic Torch by Dr. Leslie Kay.

image shows an example of how a vOICe device can look. The camera in the center is what captures the image then processed as previously mentioned.

As a last example regarding blind users, Joshua Miele of the Smith Kettlewell Eye Research Institute in San Francisco has written braille support for MATLAB and the sonification toolbox for blind engineers and scientists **Girvan2005**

Generally, all these examples of technology tell us one thing. Technologies exist in the world where people have successfully used sonification to assist in everyday situations. The examples range from critical equipment dealing with life and death, to people just getting to experience what it is like to have some sort of vision. This tells us that sonification has a wide area of use, and focusing further on sonification techniques and how weather data is perceived and displayed will give us a good basis to work from.

There are different techniques for sonification of data. These will be discussed below.

2.2.3 Sonification Techniques

The investigation of different sonification techniques will give us options and direction for when we later have to implement these techniques to sonify weather data for testing.

Techniques

One way of defining sonifications is describing them according to their sonification techniques. Alberto de Campo, University for the Arts, Berlin, Germany, has made a *sonification design map* **Hermann2011** which features three broad categorizations of sonification approaches.

1. Event-based
2. Model-based
3. Continuous

The appeal of de Campo's approach is that it allows for blurry boundaries between the categories and offers guidance for choosing a sonification technique.

In the book, The Sonification Handbook, co-authors Michael Nees of Lafayette College, Easton, Pennsylvania, USA and Bruce N. Walker, Georgia Institute of Technology, Atlanta, USA, give a brief overview of the above techniques employed in sonification **Hermann2011**

Interactivity: One of the elements to consider when discussing sonification techniques is the interactivity available (or unavailable) to the user of an auditory display. Interactivity with auditory displays ranges from completely non-interactive to completely user initiated. Non-interactive sonification is often referred to as "concert mode". In instances where the user is able to change and/or choose parameters of the display, has been referred to as "query based" or "conservation mode". User input may also be the driving factor of the presentation of the sound. "For most sonifications to be useful there must at least be some sort of interactivity, even if it is just play/pause or replay of a certain sound."

Parameter mapping (event-based sonification): "Parameter mapping represents changes in some data dimension with changes in an acoustic dimension to produce a sonification". Sound has many changeable dimension such as frequency, amplitude, phase etc. The dimensionality of these data must however be constrained such that a perceivable display is feasible. The data changes may be discrete or qualitative. For instance, and alarm may be triggered by a discrete on or off threshold, or parameter mapping can be a series of discrete data which makes it seem more continuous. These event-based techniques have a passive mode of interaction. Some event-based sonifications are brief and offer limited opportunity for user input.

Model-based sonification: The model-based approach is different from the event-based approaches in that instead of mapping data parameters to sound parameters, the developer builds a virtual model whose sonic responses to user input is derived from data. A model is a virtual instrument with which the user can interact with. The user input drives the sonification. The user learns to understand the structure based on the sonic feedback of the user's input. These types of sonification usually involves large numbers of data points and and high data dimensionality.

Audification (continues sonification): Audification is a direct form of sonification where waveforms of periodic data are directly translated into sound. For instance, a Geiger counter gives the user constant sonic feedback of the radiation level by translating data of radiation level into sound.

These are the main methods of sonification, but the different techniques might not all apply to the kind of sonification required for converting weather data. The delimitation and choice of the sonification technique(s) most suited for our project will be discussed later (see Analysis chapter).

First we must investigate which weather data makes sense to sonify. This investigation will begin with looking at different weather forecast media, in order to see what different weather informations are considered to be more relevant to the general public, as it might not be relevant or necessary to cover every aspect of weather forecast information.

2.3 Weather Data

Now that we have an overview of what sonification is and some methods of application, we will begin to investigate what weather information is and what types of weather information is usually decided by different sources as being more relevant to the user. Gathering this knowledge of popularly presented weather information will help decide which weather information is most relevant for us to sonify in order to answer the question of how far it is possible to provide adequate context for interpreting sonifications of data.

2.3.1 What is weather Data?

First off, what is meant by weather data? Weather data is derived from weather forecasting. Weather forecasting attempts to predict the state of the atmosphere for a given location, using science and technology.

> "Weather forecasts are made by collecting quantitative data about the current state of the atmosphere on a given place and using scientific understanding of atmospheric processes to project how the atmosphere will evolve on

that place." **Wiki2014-1**

Weather forecasts are used for a variety of different purposes. For instance, weather warnings used to alert societies of dangerous weather, precipitation and temperature is important in agriculture, road surface conditions is important to traffic etc. On everyday basis, weather forecasts are used to determine what clothes to wear, traffic and travel time, and to plan outdoor activities on a given day. Nowadays weather forecasting relies on computer-based models that take many different atmospheric factors into account **Shuman1978** There is a big range of different weather data, some of these are:

- **Temperature/Dewpoint** - Current air temperature 2 meters above terrain.
- **Wind speed** - Average wind speed over 10 minutes, 10 meters above terrain.
- **Wind direction** - Average wind direction in degrees.
- **Air pressure** - Pressure at sea level measured i hPa (Hectopascal).
- **Humidity** - Current relative humidity measured 2 meters above terrain, measured in percent.
- **Precipitation** - Rain/sleet/snow/hail over the past ten minutes measured in mm.
- **Sun hours** - Hours with sun in a day.
- **Pollen Forecast** - The potency of the pollen.
- **Sunrise / sunset** - Time of day where the sun rises and sets.
- **Cloud cover**
- **Wind chill** - The winds effect on air temperature.
- **Visibility** - How far can you see with clear line of sight.
- **UV-index** - Intensity of UV radiation.
- **Fronts**
- **Source Regions** - Where the air is coming from.
- **Drought** - Risk of drought. Presented as a scale.

These are just some of the weather data available in modern weather forecasting. Not all of these are necessarily relevant to one single individual, and weather forecasts meant for the general public (not fields of work/study that require very specific weather data) limit the amount and range of weather data presented for the sake of clarity and time (both to present the information but also the time required by the individual to get the information relevant to most). Below are some examples of what types of weather data have been chosen to be presented to the viewer on certain weather websites and popularly used weather applications. This weather information will later in the report be delimitated for testing purposes of the challenge of providing adequate context for interpreting sonifications of the weather data.

DMI.dk (Danish Meteorological Institute)

DMI.dk is the website of the danish national meteorological institute. It is arguably the most well known website containing weather information, in Denmark. The website contains a huge amount of weather data, which makes it a bit difficult to navigate and find even the basic weather forecast of the day/week. Navigating through the site you will however be able to find information about the atmosphere in a given region such as: radar images of precipitation, satellite images, lightning probability, ozone measurements, snow depths, and drought indexes, in addition to the more standard weather information such as wind speed, temperature, precipitation (represented as a graph) and so on.

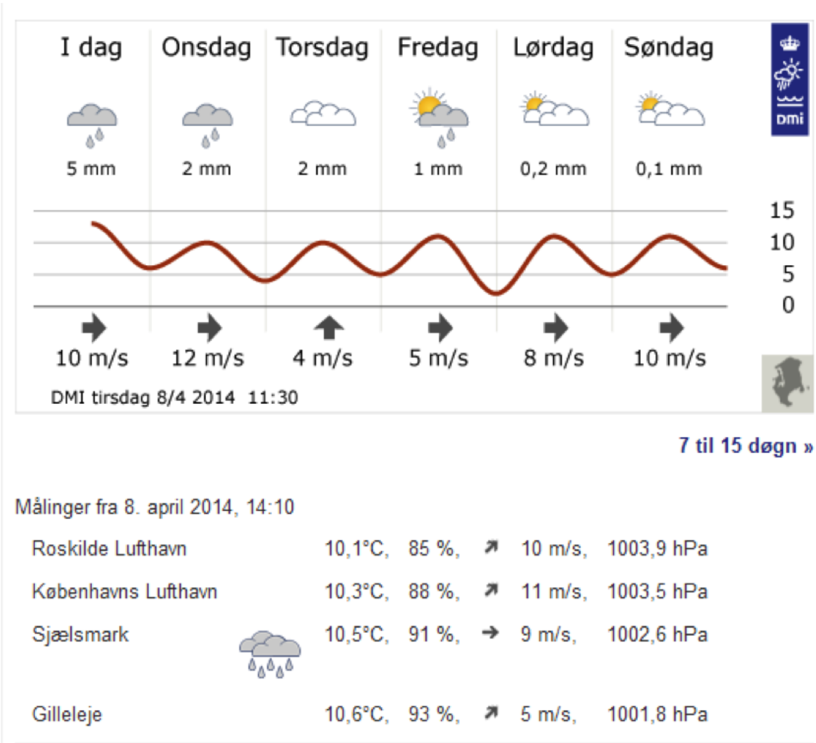


Figure 2: 7-day forecast from DMI.dk

However, in order to give a shorter, but more clear forecast, you have the option to get a graphically presented 7-day prognosis (Figure 2).

This is the basic weather data chosen to be relevant to the general public, and thus this is the prognosis we will be comparing with the other forecasts. The 7-day prognosis on DMI.dk contains information about:

- Precipitation
- Cloud cover
- Temperature
- Wind speed
- Wind direction

Additionally, information measured at a certain point of the current day at predetermined locations (April 8, 2014 - 14:10) is presented:

- Temperature
- Visibility
- Wind direction
- Wind speed
- Atmospheric pressure

There is also a summary of the current day's forecast.

TV2 Vejret App

TV2 Vejret is a weather app developed by danish TV channel TV2 for iOS and Android. The app pulls weather data directly from the TV2 weather center, where the TV stations meteorologists work on predicting the weather for the TV2 news, website and the weather app.

The app finds the phones current location via GPS and retrieves weather information about that area. In terms of relevant data, the app gives a fairly limited amount of information (at least compared to DMI.dk), but covers the basic data such as:

- Precipitation
- Wind speed

- Wind direction
- Sun up/down
- UV index
- Cloud cover
- Temperature

From figure 3 it is apparent that most of the information is only presented for the current time of day. Prognosis for the next 14 days is limited to:

- Cloud cover
- Temperature
- Precipitation
- Wind speed
- Wind direction

Figure 3: TV2 weather app

The app does not however provide radar, heat maps or other more advanced features. It has the typical amount of information about the weather for an app, but where the app sets itself apart from the competition, is due to the fact that it is a TV-channel app.

This means that the app contains video streams of the latest weather forecasts from TV, and other weather related news. This can be useful if you want a more detailed forecast with certain highlights about the current and forthcoming weather.

Yahoo Weather

Yahoo Weather is an app for iOS and Android which shows the weather in your current location, or if you want, in other locations around the world as well. The app contains a lot of the same information that other weather applications do, it is the design of the interface and layout which sets it apart from other apps. The application has received the ''Apple Design Award" because of it's aesthetics. One of the features of the design, which has gotten a lot of praise, is that the app finds beautiful images of your location on Flickr (an online image database), taking into account the time of the day and current weather condition, of your location and the photos, and uses these as the background of the weather information. Aside from this unique approach to visually presenting you surroundings, the interface itself was also very well received by critics.

In addition to having a very manageable interface, the app actually also contains a great deal of detailed weather information. This data includes:

- Temperature
- Cloud cover
- Precipitation
- Probability of downpour (percentage)
- Wind Speed
- Wind direction
- Pressure
- Chill factor
- Humidity
- Visibility
- UV-index
- Sunrise/sunset
- Moon position

- Heat map
- Wind map
- Satellite map

Again, as with the TV2 Vejret app, most of the detailed information is only available for the current time on the current day. For the 5 and 10 day forecasts there is only information about:

- Cloud cover
- Day/night temperature peaks

Because of the apps very minimalistic design approach the screen is not overloaded with all sorts of data about the weather. It uses subtle animations eg. a windmill spinning at a rate according to the current wind speed to illustrate more palpable information about the wind speed. Another way the application tries to present information relevant to the user, is by adding customization. The user can drag the different modules around to bring the most viewed ones to the top of the screen, limiting the amount of scrolling around to get information you want.

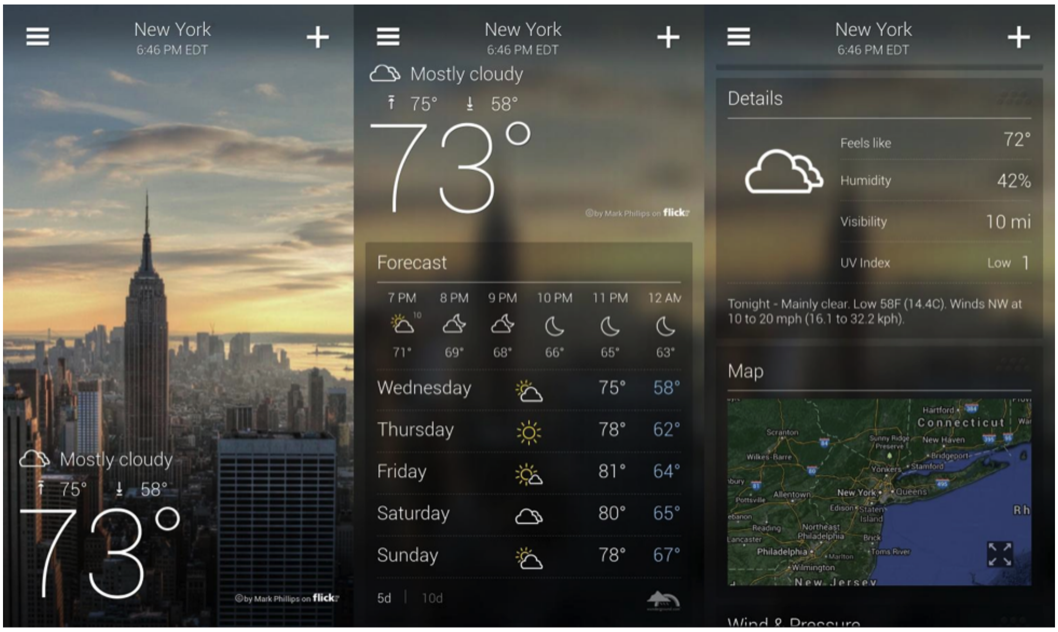


Figure 4: Yahoo weater app

So all in all, the app does contain a lot of information about the weather, and instead of the developers delimitating the information and deciding which weather data i relevant to the user, they allow the user the option of customizing the app, deciding themselves what information is relevant.

InstaWeather

InstaWeather is a weather application that focuses a lot on being a visual application. The amount of information about the weather depends on which skin to the application that you want to use. The information given can be limited to only being the temperature, a symbol that shows the weather condition and a small forecast. Some skins can also be very detailed and give information air pressure, temperature, rain, wind power and direction. The app is very customizable so you can change pictures so it feels more personal. The main feature in this application is that it borrows the picture sharing ability from Instagram. This means that the user can take a picture and send it to a friend with weather information added to the picture.

Figure 5: InstaWeather

It is difficult to write about what relevant weather information is in regards to this application, because the user wholly decides for him/her self, what that is. It is in some way the most relevant weather information can be to a specific user, if that person puts in the time to customize the application for his or her needs. It does not however tell us much about what is in general considered to be chosen as relevant weather data.

Which weather information to be sonified for our test will be decided later in the Design chapter through user testing.

2.4 Final Problem Statement

Now that we have an idea of the process of sonification, and having revised typical visually presented weather forecasts and their content, we have to find out whether it is possible to provide adequate context for interpretation of weather data with the use of sonification. This will be investigated by comparing to visual data presentation in order to see to what extent it is possible to provide an understanding of these data as non-speech audio. This brings us to the final problem statement:

“To what extent is it possible to convey weather information, solely as a nonspeech auditory display, using sonification techniques, and be as intuitively understandable as visually presented weather information, where intuitive is defined as knowing by intuition?”

3 Analysis

In this chapter we will look into the advantages and disadvantages of sonification. Some of the advantages to consider are mentioned in the previous chapter, and so the advantages in this chapter will mainly be regarding using sound to convey data. We will also look into different contradicting terms in relation to sonification. Lastly, we look further into the sonification techniques that are available to us. This is so we can delimit what techniques we are to use when presenting data during our test. The advantages and disadvantages are so we know what to look out for in this regard.

3.1 Advantages and Disadvantages of Sonification

There are several advantages for sonification. Not only can it represent data and learn patterns and cycles in said data, but it can also aid the disabled and assist workers in different fields with sound patterns and alarms (Section 2). However, as with everything there are certain disadvantages of sonification. The disadvantages can all be lead from the same disadvantages that sound has. Sound can be frustrating or annoying for some users, as people are forced to impose their own taste and ideas subjectively on data. Sound is also incredibly hard to describe in certain cases, you cannot mimic sound or make others interpret data without them being able to hear it. Listening to sound representing data can require learning or inherent talent, and this learning can take a longer time than looking at visually represented data, although that depends on the type of data. The type of data represented also needs to be taken into account for whenever a sound or pattern is chosen. "It is hard to represent a spatial arrangement with sound. You need to use the appropriate display." Said Bruce Walker, a professor in the schools of psychology and interactive computing at Georgia Tech, running a group called the sonification lab **Feder2012** To give a more concrete example of an advantage, sonification was used to study a model of an artificial heart pump, where a modulated sound was indicating pressure on a pusher plate, and a tapping sound indicated a blood cell entering threshold vorticity, and a drum indicated the opening and closing of heart valves. It was reported that it seemed easier to determine different things, such as the frequency of blood cells crossing and detecting whether or not the heart valves were opening or closing. This is in contrast to the standard method of looking at change in color on a monitor. Another example is sonification used to indicate seismic events caused by the fracturing of rock walls during a 3 month dig. The engineers had a visualization to indicate these fractures, but the events were short and to address this, they added a short sound that varied in volume depending on the magnitude of the event. The sounds would draw more attention to periods with more seismic activity, making it easier to detect overlapping events that indicate higher risk. Sounds are extremely useful when variables do not appear together in the same image, or require shifting visual attention from monitor to monitor. From these two examples, it is clear that when dealing with data that has a variety of events or over longer periods of time, using sound can make the data easier to comprehend.

With examples of advantages and disadvantages in the representation of data through sonification, and how it is used, it is also valid to research existing types of sonification that represent weather data. This will give indications towards pre existing solutions to sonification of weather data, and might enlighten plausible methods of how we should develop a prototype.

3.1.1 Weather data represented using sound

Engineers use visualizations to represent a large amount of data over complex systems, an auditory display can be useful in these cases, where the interpretant needs to keep his eyes focused on the visual data while also receiving data from an audio source. The quality and completeness of a fluid flow simulation was analyzed by comparing the sonified audio data generated by a simulated turbine and an actual recording of a turbine **Barrass1999** Sounds can make it easier to perceive cycles and rhythm, and also abnormalities in a large amount of data. Another example of a visualization designed by Simon Kravis at the CSIRO was made to assist the engineers planning a water treatment, works by using a computer model. Chemical concentrations in the river's water are shown by various colored segments, according to the downpour over a one year period. They realized that it is difficult to watch the downpour graph and the river visualization at the same time, so they decided to add sonification to represent the downpour so that an engineer may pay less visual attention to the river, while quantities of the downpour are represented by rain-like sound. The result of this was that after several repetitions, an engineer could learn the patterns of the rainfall over the year and can anticipate cycles in downpour or dryness. The sound representation is meant to bind the different sets of visualizations together and make it easier to remember, and an engineer was able to make relations between chemicals that are never seen at the same time **Barrass1998**

3.2 Analogic vs Symbolic representation

There are many different ways to go about designing something that uses sonification. Methods for designing auditory displays have been classified along a spectrum between analogic and symbolic by Kramer **Barrass1999** "An analogic representation is one in which there is an immediate and intrinsic correspondence between the sort of structure being represented and the representation medium." Meaning, there is one to one mapping between points in the data and points in representation space **Barrass1999** Examples for this include a Geiger counter or an auditory thermometer.

Its counterpart, symbolic representation, categorically denotes the thing being represented and relations within the representation do not necessarily reflect intrinsic relationships in what is being represented. Examples of a display like this are computer beeps, cell phone alarms and vehicle control notifications.

3.3 Semiosis

Semiotics is the study of signs and their creation and interpretation. Signs can be anything from images to words, sounds and smells. These signs have no inherent meaning other than the one we attribute to them. Modern semiotics is based on the work of two major figures, Ferdinand de Saussure and Charles Sanders Peirce, a Swiss linguist and an American scientist respectively **Vickers2012** In Saussure's view the sign system is a dyadic relationship between a "signifier" and a "signified". A signifier is typically a sound pattern, and a signified is the meaning that signifier carries. An example of this is the symbol `/cat/`, which in this case is a signifier for the concept or meaning that we know as a cat. The link evoked between the sound pattern and the meaning is the resultant sign. Peirce considered this relationship to be insufficient, and he proposed another scheme in which an object referred to is represented by a "representamen" which then evokes in the mind of the listener the meaning of the sign which he refers to as the "interpretant". The two theories loosely refer to one another and can be shown as such **Vickers2012** (Figure 6):

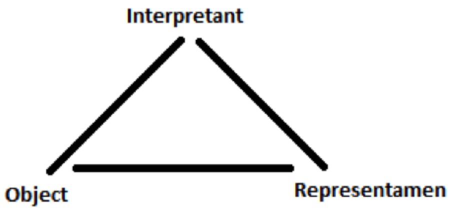


Figure 6: Semiosis

3.4 Sonification usage

Sonification can be split up in 4 different kinds of function types, when going by theory created by Bruce N. Walker and Michael A. Ness **walker2011** The 4 different types are as follows:

1. Alarms, alerts, and warnings
2. Status, process, and monitoring messages
3. Data exploration
4. Art and entertainment

Alerting functions Alerting functions refers to sound indicating that a certain event is occurring or has occurred, but it usually won't convey descriptive data on the alerted subject. For example, a microwave oven makes a beep when the timer has expired, but it will not tell you if the containing substance is done or overcooked. Another example is the usage of calendar notifications on phones or tablets. These notifications will only notify you that something is going to happen by ringing or beeping. To further understand what the occurring sound means, a visual clue or a memory of the upcoming event is required.

The last example in this category is a fire alarm. A fire alarm will ring loudly to alert you that you need to move immediately, in most cases out of the building, but it does not contain any information about the location of the fire, nor does it tell you how severe the fire is.

Status and progress functions Status and progress function has a purpose similar to that of alerting functions, but to understand the data correctly, a visual display or another form of continuous data is required to fully understand the situation at hand. It requires the interpretant to pay attention to small changes in the auditory feedback.

This relates to the example given (Section 2.2.2) that we have previously discussed, where surgeons focus their eyes on the patient while listening to the heart monitors.

When designing a weather application, this could be the function to use if your goal was to have mostly visual data, only supplied by auditory data. However, it is important to note that when using this type of sonification, the auditory display itself is only a sub part of the data.

Data exploration functions When talking of sonification, this is the function usually referred to. Data exploration is meant to encode and convey information about entire sets of data, or relevant aspects of said data. Sonification designed for data exploration is different from status or process indicators, seeing as they use sound to offer a more "holistic portrait" of the data, as opposed to condensing information to capture a momentary state **walker2011**

Art and Entertainment Since the sound producing capabilities of computers have evolved exponentially over the past years, so have the music producing of computers too. Sound data like sonification have been adapted more and more in to the world of music, and more artist uses data mapping included in their song or tracks. Since music does not really convey any form of information, it can still be included in the sonification functions, since it still conveys the expression/data of art and entertainment.

The above covers the different sonification functions, and in which cases they can be useful to alert or notify interpretants.

The above covers the different sonification functions, and in which cases they can be useful to alert or notify interpretants. As stated above, sonification has a lot of functioning abilities regarding how you can use audification without speech to notify a user what happens around them without using their eyes or hands, but sonification can also be categorized in their techniques and how you approach them. So far we have only explained what sonification can be used for, but not how the techniques are in practice, does it require interaction from a user or not?

Those approaches can be categorized in 3 categories which are (1) event based, (2) Model Based (3) Continuous.

Event-based sonification The Event based approach is where the data of the sonification display is employed by the parameter mapping. Parameter mapping are changes in data dimension with changes in an acoustic dimension to produce a sonification. Parameter sees changes in data and then try to convey that data with as much as a feasible display through sounds, to show what that data means, a lot like what we want to do with data of the weather. The event based approaches have more or less through time, had a passive interaction possibility with brief notification like alarms and notification, but event based sonification that employ parameter mapping have the possibility to adapt to both passive and active interaction.

The sonification Handbook **Hermann2011** shows several examples of sound that tells the user e.g. that their target destination is reached. The data will read the remaining length of the journey and then intensify the sonification/sound depending on how close you are to your target.

Model-based sonification Model based differs from event based a lot, since here you need a virtual model that relies heavily on the interaction between the user and the virtual object. The virtual object then reads the users interaction, and converts that interaction into sonification.

The Sonification Handbook video number 16.3 **Hermann2011** shows a perfect example of model based sonification. You see a user with a triangular object moving around, the software then detects his movement and convert his actions in to sounds depending on how the object is moved. Another example of this can be a metal detector, which some people uses on the beach to scavenge forgotten objects on the beach. The metal detector will notify/alarm you if your metal detector senses any metal beneath its reader.

Continuous sonification Continuous sonification is possible when data are timed series and sampled at a rate that a quasi-analog signal can be directly translated in to sound (quasi-analog signal in telecommunication is a digital signal that has been converted to a suitable form for transmission through analog channel). To explain it more simply is when sound waves are directly translated in to sound. That means the conversion happens when the software translates the data from a sound wave into sound e.g. a Richter scale converts seismic data in to wave forms. The wave forms are displayed with an accuracy of 90%.

We will generally focus on the first category of sonification, but not in the sense that we need to alarm people. We know that sonification can notify you in many different ways. Some forms require a passive listener and some requires and active listener, maybe both. The approaches for sonification are also different depending on the task or the message you wish to convey. We also know that sonification can have interaction methods that require the user to physically interact with an object to generate sonification to work. According to our research regarding sonified weather data, it is stated that engineers needed to become familiar with the sound to know the intensity of the rain. We will therefore expect that if the users are hearing the sound for the first time, they may not give the correct answer.

For the prototype we will be using event based sonification. Continious sonification could also be used, if we were to take weather data and directly transform it into sonification, but this will not be the case in the prototype. The type we will be using is data exploration, since we wish to translate weather data into sounds that can be heard by the end user during testing. Using event based sonification means we will employ parameter mapping. Theoretically this would mean that we have the ability to change the sound as our weather data changes, which seems to be the ideal choice. So to summarize what we have learned and what we will use in our prototype, we will dive right into a list of requirements.

4 List of Requirements

The content of the list of requirements is to be seen as parameters for the prototype design. The arguments have been refined in the analysis-chapter, and have ultimately led to these requirements, that will help construction of the final prototype. Hence it is to be considered a blueprint from which numerous variations of designs can be crafted.

General requirements:

- The prototype must contain sounds that range in different levels within the same weather category.
- The visuals provided in testing must be based on results from either pre-testing or SOTA analysis.
- The sounds will have a meaning attached to them (i.e. semiosis)
- Symbolic representation is used to convey our message about the weather
- Will use the type "data exploration" of sonification to translate weather data into sound

Program functionalities:

- Able to import sound file
- Able to play sound file
- Able to pause sound file
- Able to change the tempo of the sound
- Able to add filters to the sounds

5 Design

In this chapter we will look at the design of the prototype, which will be used in our test to try and answer the FPS. The design will be based on the list of requirements (see Analysis chapter). We are also going to take a look at the delimitation of our weather categories (e.g. temperature, wind speed, precipitation...). Based on the requirements and delimitation, pre-tests will be designed and carried out. These tests will then lead into a design blueprint of our prototype.

From the list of requirements it should be possible to plan how the prototype is going to fulfill these. Additionally, the weather categories have to be delimited into a realistic amount of weather conditions which suits our timetable. After the delimitation the visual and auditory elements will be chosen from the results of pre-testing. When the sounds and pictures are in place, it is time to create the blueprint of what the pictures should look like and how the sounds are going to be made. Figure 7 describes the process of the actual design of the prototype.

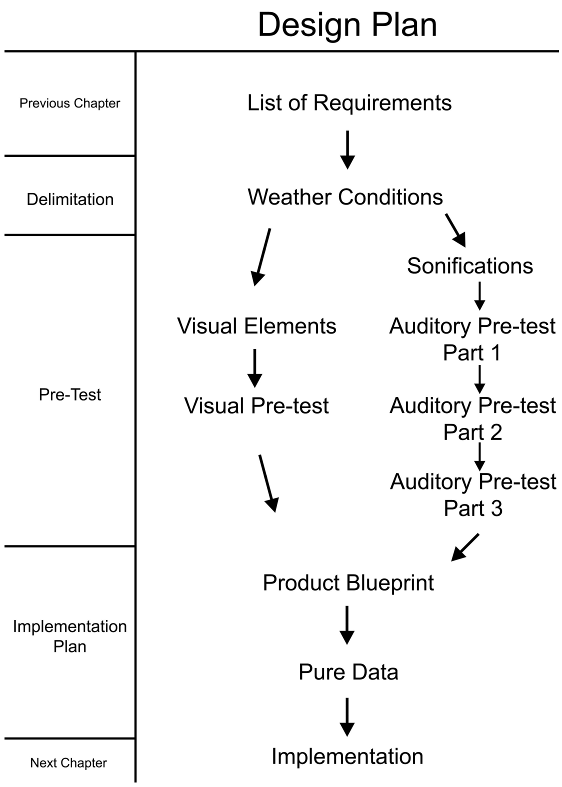


Figure 7: Plan for design process

5.1 A design to meet all the requirements

To get an overview of how the requirements are going to be fulfilled, the requirements have been split up into two categories. Requirements for testing and requirements for the prototype itself.

5.1.1 Testing

General requirements:

- The prototype must contain sounds that range in different sound-parameters within the same weather category, such as varying amounts of rain.
- The visuals provided in testing must be based on results from either pre-testing and/or SOTA pre-analysis
- The sounds must have a meaning attached to them (i.e. semiosis)
- Symbolic representation is used to convey our message about the weather

We have decided to have a pre-test to decide on the images to be used in the prototype. This test involves test subjects to draw a given weather category (e.g. a drawing of certain amount of wind speed etc.). To decide on the sounds for the prototype it was decided to make a three-step test.

First step was making an interview that got us an idea of what sounds to use. The second step was to make a another interview where people had to recognize the sounds that we had chosen, based upon the first pre-test. The last pre-test was to establish what value the test subjects associated with the specific weather conditions.

The first two pre-tests define the sounds/sonifications for the weather conditions. The last pre-test describes if the sonifications formulate the desired values of each weather condition.

5.1.2 Prototype

Program functionalities must be able to:

- Import sound file
- Play sound file
- Pause sound file

- Change the tempo of the sound
- Add filters to the sounds

We have decided to use Pure data[1] since we already have some knowledge in this program and know it can fulfill our requirements.

5.2 Weather Conditions

There are a lot of different kinds of weather data. Since it is not possible to cover every single category of weather data within the projects time limit and because information such as radar maps do not really lend themselves very well to sonification, we decided to make a delimitation of the weather data.

Based on the research from the weather applications (See Pre-Analysis section 2.3) the following raw weather data list was created.

Raw list of weather data

- **Temperature/Dewpoint** - Current air temperature 2 meters above terrain.
  - Day temperature
  - Night temperature
  - Average temperature
- **Wind speed** - Average wind speed over 10 minutes, 10 meters above terrain.
- **Wind direction** - Average wind direction in degrees.
- **Air pressure** - Pressure at sea level measured i hPa (Hectopascal).
- **Humidity** - Current relative humidity measured 2 meters above terrain, measured in percent.
- **Precipitation** - Rain/sleet/snow/hail over the past ten minutes measured in mm.
- **Sun hours** - Hours with sun in a day.
- **Pollen Forecast** - The potency of the pollen.
- **Sunrise / sunset** - Time of day where the sun rises and sets.
- **Cloud cover**

[1] http://puredata.info/

- **Wind chill** - The winds effect on air temperature.
- **Visibility** - How far can you see with clear line of sight.
- **UV-index** - Intensity of UV radiation.
- **Fronts**
- **Source Regions** - Where the air is coming from.
- **Drought** - Risk of drought. Presented as a scale.
- **Downpour** - Rain in mm.

After going through the data on the raw list we found that many of the weather categories didn't fit the project. So we decided to only use relevant weather data that people normally would use in an everyday situation. This delimitation is based on our research on what weather data there is available in the weather apps (See Pre-Analysis section 2.3).

List of relevant data

- **Temperature/Dewpoint** - Current air temperature 2 meters above terrain.
  - Day temperature
  - Night temperature
  - Average temperature
- **Wind speed** - Average wind speed over 10 minutes, 10 meters above terrain.
- **Wind direction** - Average wind direction in degrees.
- **Humidity** - Current relative humidity measured 2 meters above terrain, measured in percent.
- **Precipitation** - Rain/sleet/snow/hail over the past ten minutes measured in mm.
- **Sun hours** - Hours with sun in a day.
- **Pollen Forecast** - The potency of the pollen.
- **Wind chill** - The winds effect on air temperature.
- **Visibility** - How far can you see with clear line of sight.
- **UV-index** - Intensity of UV radiation.

- **Downpour** - Rain in mm.

Going through the relevant weather data we again decided that the list was too long and could create problems further into the project do to limited resources and the fact that we would still be able to answer our FPS with the delimited data. Therefore, we decided to make another delimitation. The list was further delimited based on our thoughts of what an average person would need to know in an everyday scenario, so the list of data does not necessarily represent the weather categories required to create a functional weather app.

List of delimited weather data

- **Temperature/Dewpoint** - Current air temperature 2 meters above terrain.
  - Day temperature
- **Wind speed** - Average wind speed over 10 minutes, 10 meters above terrain.
- **Precipitation** - Rain/sleet/snow/hail over the past ten minutes measured in mm.
- **Pollen Forecast** - The potency of the pollen.
- **Visibility** - How far can you see with clear line of sight.
- **Cloud Cover.**
- **UV-index** - Intensity of UV radiation.
- **Downpour** - Rain in mm.

5.2.1 Categories

Now that the list had been delimited, it had to be converted into a design that made sure it was easy for the test subjects to answer the questions. We did not use Continuous Sonification (See analysis section 3.4), because it is hard for people to interpret numbers, for example: “Could you make a sound based on a temperature of 12 degrees?”. Since it is not possible for us to go through every degree of e.g. temperature, the numbers were converted into three categories: Low, Medium and High. We also decided that the following weather data: Pollen and Visibility, should act like a warning indicator. This means that the sound should only be played above or below a specific value. This decision was made since there is no reason to warn people about dangers when there is none. In this case Pollen will be played when there is a high amount of pollen, and Visibility will be played when there is low visibility.

Now that the values have been decided , the values have to be assigned. We are getting our Low, Mid and High value from DMI[2].

Category	Low	Medium	High
Temperature	0'C	15'C	30'C
Wind Speed	5 m/s	17 m/s	32 m/s
Pollen Forecast	0 - 30		30 - 100
Visibility	10 m		10 km
Downpour	0 mm	3 mm	10 km
UV-index	3	3 - 6	7 - 8

Table 1: Category values

5.3 Visual pre-test

A pre-test was done to identify the common visual associations often used with the weather forecasts, these associations will form a basis for the visual implementations. The visual implementation will contain images of certain weather conditions that people should find intuitive.

The test took the form of a simple interview where the subject was asked to draw certain weather conditions.

Because the test has no target group other than people who have at some point checked a weather forecast, the test will be conducted using random sampling. Random sampling selects every subject in the test from a greater group of subjects (the target group) completely at random. Every subject has an equal chance to get picked to do the survey.

The selected subjects would be given a piece of paper with three empty frames. The subject was then asked to draw the first thing that came to mind when told about a weather condition. A sample question could be: "draw the first thing that comes to mind when i tell you that it is 30*C outside". The subject would then draw their association. The subject would then be asked to make another drawing of the same weather condition but with a different value. i.e. if the subject had first been asked to draw a hot day, they would then be asked to draw a cold day and then an average day.

[2] `http://www.dmi.dk/vejr/til-lands/byvejr/by/vis/DK/1000/K%C3%B8benhavn,%20Danmark`

5 people for each weather condition was asked to participate, 35 in total. The complete drawing sheet and answers to the survey can be found in appendix A.

Condition	Value	Possible solution	Alternate solution
Temperature	Low	Snowflake, snow	
	Medium	Average clothing	
	High	Sun and beach	Thermometer
Downpour	Low	Sunny	Clouds, no rain
	Medium	Clouds with rain	
	high	Clouds with much rain	
Wind speed	Low	Tree/Flag, no movement	
	Medium	Tree/flag, some movement	
	High	Tree/man, much movement	
Pollen	Low	Man, happy/smiling	
	Medium	Man, Sneezing	
	High	Man w. runny nose, red eyes, itching	
Visibility	Low	Window, gray outside	
	Medium	Gray colors	cloudy
	High	Clear day, sun	
Cloud cover	Low	Clear day, sun	
	Medium	Few Clouds	
	High	Overcast	
UV-index	Low	Cloudy day	
	Medium	Clouds, sun	
	High	Sun, no clouds	

Table 2: Possible visual implementations

Table 2 shows the possible solutions for the visual implementation. The drawings were analyzed for common traits within the same condition and value, i.e. if two or more drawings of the same condition and value would contain a person, this would be interpreted as a possible common association and be included as possible solution.

5.4 Sound pre-test

The idea of the pre-test is to determine what sounds to choose when looking for the optimal choice of sounds. We will go through a three step audio pre-test that will provide us with the information we need. The first step is meant to give us insight about what sound to use. The second step is to test these previously mentioned sounds to see if people recognize what it is meant to represent. The third step is to play the sounds for them and then ask what weather data these sounds represent, in a setting where we have already specified the weather category.

5.4.1 Audio Pre-Test - Part One

This first part of the pre-test was meant to give an idea of what sounds to use according to the feedback given from interviews. We then provide our own thoughts in addition to determine what the sounds should be.

Purpose

Determine what sounds to use in further testing.

Description

Part one was performed by interviewing people randomly selected around the AAU campus. This part of the pre-test contains questions about how the testers would describe the different weather categories with a sound or a scenario, both for high and low. This information is then used to pick out the sounds for the upcoming part 2.

Amount of participants:	12 test participants
Test subject sampling:	Convenience sampling: Aalborg University students.
Estimated length of test:	Around 10 min per test subject.
Test location:	Area on and around Aalborg university.
Date and time:	When appropriate.

Results

See appendix B.1 for results.

These results have been placed together for each category, where you can see answers for both high and low values.

Evaluation

When analyzing the data that has been gathered, it was seen that most of the categories have the same answers. Our sounds were based on a mix of how the majority wanted the sounds to be like and what we believed could be a recognizable sound. The following is an overview of our thought process.

Temperature *High:* We noticed that a high pitched sound was a frequent answer among the participants. We went with this in mind when choosing the soun. The sound that we ended up choosing, was inspired by one of the participants that answered "a boiling kettle".

Low: The majority answered “breaking ice” and “snow”, but since we are using that for Precipitation - Snow it is not an option. We instead went with the “teeth grinding” sound.

Wind Speed *High:* A “high wind gust” seemed to be the most common answer, so that is what we went with. *Low:* A “low wind gust” seemed to be the most common answer, so that is what we went with.

Precipitation *Rain:* All the answers to this were “rain”, so we went with rain as our sound. *Snow:* Most of the answers to this were “snow”, but since snow does not have a sound then we went with footsteps in the snow. *Hail:* All the answers to this were “hail”, so we went with hail as our sound.

Pollen Forecast *High:* “A sneeze” was the most common answer, so that is what we chose as our sound. *Low:* Because we are going with pollen as a warning indicator this question was only stated to satisfy our curiosity. The test participants did not give any real responses to this question.

Visibility *Low:* Most of the people we asked described a foggy scenario as seen in movies. Since this is the scenario most people think of, we chose a “fog horn” sound to remind them of this scenario in the hopes that they would associate it with a foggy day.

5.4.2 Audio Pre-Test - Part Two

Purpose

The second part of the pre-test is based upon the results given from pre test 1 (See section 5.4.1). The results has been evaluated, and sounds that could be used as a sonification of the specific weather conditions has been found/developed. The following test is conducted as we want to ensure that the chosen sounds actually represent the results from the previous test and can be used in the designated prototype. The test will elaborate upon the sounds and will make it possible to evaluate whether the sounds are understood or not, and what the test subjects think that the sounds intuitively implies.

Description

The procedure of the test was conducted in the following manner. A single test subject was asked to listen to the acquired/constructed sounds, and was then asked to write down what he/she relates to the sound e.g. what the subject thought of the sound actually implies. The test subject was given no prior information to the test, and was unaware of everything but the test procedure. This ensured that the test subject was given no information that could be used to assume anything based upon the sounds and somewhat bias the results, as we were looking for the intuitive understanding of the presented sounds.

Amount of participants:	10 test participants
Test subject sampling:	Convenience sampling
Estimated length of test:	10 min per test subject.
Test location:	Area on and around Aalborg university.
Date and time:	When appropriate.

Results

See appendix B.2 for the acquired test results.

"List of sounds" represents the sounds that were played to each individual test subject in that specific order. "Test x" represents answers written down from each test participant in each column, where the data represents the denoted answer from the test participant. The right sided column to each test section represents the interpretation of results.

The result interpretations are divided into three categories:
Correct - Represents a correct answer.
Correct() - Represents an answer that is associated with the correct answer, as decided by us, and is therefore marked as correct. The associations are deemed correct by us and does not represent a scientific decision.
Incorrect - Represents an incorrect answer. Either the sound was not guessed, indicated by "-", in the test results, or the responses was not in any way associated with the sound, as deemed by us.

Evaluation

Table 3 illustrates the amount of correct answers in percentages.

1. **Hail** - The majority of test subjects answered "hail", which was the desired implication of the sound. We suspect that when the test subjects are aware of the subject, being weather - and thereafter will have to guess what the sound implies - the sound will suffice.

2. **Rain** - All test subjects answered correctly, therefore the sound is deemed to require no alterations or changes.
3. **Snow** - A low amount of test participants, around 10%, was able to associate the sound with snow as intended. We therefore chose to replace the sound.
4. **Birds** - A majority of 60% answered correctly. This indicates that while most answers correct, adjustments might ensure that a larger percentage of test subjects will answer correct. Plausible alterations will be decided by us.
5. **Horn** - A Majority of 90% answered correctly. Therefore no alterations will be made.
6. **Sneeze** - A Majority of 90% answered correctly. Therefore no alterations will be made.
7. **Kettle** - A Majority of 90% answered correctly. Therefore no alterations will be made.
8. **Teeth** - No test participants were able to answer correctly. Therefore we will replace the sound.
9. **Small breeze** - The majority of 70% was able to answer correctly. Adjustments will be made, and might ensure that a larger percentage of the subjects will be able to answer correct. Plausible alterations will be decided by us.
10. **Wind** - All test subjects answered correctly, therefore the sound is deemed to require no alterations or changes.

	Sound	Answered correctly	
1.	Hail - Downfall hail	70%	7/10
2.	Rain - Downfall rain	100%	10/10
3.	Snow - Downfall snow	10%	1/10
4.	Birds - Downfall nothing	60%	6/10
5.	Horn - Fog	90%	9/10
6.	Sneeze - Pollen	90%	9/10
7.	Kettle - High temperature	90%	9/10
8.	Clattering Teeth - Low temperature	0%	0/10
9.	Small breeze - Medium temperature	70%	7/10
10.	Wind - Wind speed	100%	10/10

Table 3: Pre-test 2 evaluation

5.4.3 Audio Pre-Test - Part Three

Since the previous part of the pre-test we replaced the LowTemp sound (Teeth) with a new sound that has been tested around the campus and is being deemed ready for use. A small delimitation has also been made to downpour. It now only covers rain since we encountered a problem that we didn't think about at the early stages. The problem was that we designed downpour to be changed by play speed of the sound, and the only sound capable of being modified in this manner is rain.

Now that every sound has been deemed ready for use, we are able to proceed into the third step of the pre-test. In this step we are going to play the sound and give information about what weather category it is. We then want our testers to answer what weather data type they believe the sound represents.

Purpose

The purpose of this part of the pre-test is to make sure that our sounds are recognisable with a weather data type when combined with a weather category.

Description

Amount of participants:	10 test participants
Test subject sampling:	Convenience sampling
Estimated length of test:	15 min per test subject.
Test location:	Ballerup, Albertslund, and Aalborg university.
Date and time:	When appropriate.

Results

See appendix B.3 for results.

On this list it can be seen what each test person answered to the sounds.

Evaluation

Most of our sounds were recognisable and provided the people testing with the right information.
There were a few sounds (listed below) that gave us some negative data.

TempMed: People gave many different answers for this sound. This is a problem and this sound has to be replaced and tested once more.

Pollen: Most of the people got the correct weather category but some also answered "cold". Since it is a sneeze this is something that we should have expected. We will try to modify the to make sure that test participants make a clearer association to pollen.

Fog: All the people that answered the question got the answer correct. However, we also had some people who were unable to answer the question. We conclude that they might know what the sound is but don't connect it into that foggy scenario that we imagined people would in the first part of the pre-test.

After making the proper adjustments to the sounds, we feel that we are at this point ready to implement them, and use them for further testing.

5.5 Product Blueprint

Now that the visual and auditory elements have been determined upon, it is time for us to plan how to make use of the acquired data.

5.5.1 Visual Elements

The visual design is based on the table from the visual pre-test (Table 2). We use the information from our user pre-test, where to test subjects had to draw how they imagined a certain weather condition to be illustrated, to come up with similar illustrations for weather conditions in the prototype.

5.5.2 Audio elements

Now that the different sounds for weather categories were in place, the next step was to figure out how to make these sounds fit into our value categories. Most of the sounds can be placed and played under the fitting values, but rain (Downpour) and wind speed had to be changed in order to let people know if it had a low, medium or high value. In order to change these sounds we decided to use Pure Data. With Pure Data it was possible to change the speed of the sound and add filters so the sounds that were able to fit into our value categories.

Here is the Pure Data objects we will use for the implementation:

Band Pass Filter Band Pass Filter also called [bp] in pure data, is a filter that only allows some range of frequencies between the highest and lowest. It has three inputs. The first one is the input from the audio. The second input is for the center frequency that will be allowed to pass. The third input is the resonance, which determines how wide the ranges of frequencies that are allowed to pass through the filter are. The function is that the center frequency will be unchanged, but the frequencies, higher or lower, will be reduced or removed from the sound.

Sample A sample refers to a value or multiple values that is set to a point in time.

Metro An object that keeps calling after a specific amount of time (in milliseconds).

Phasor A phasor is a representation of a sinusoidal function. This function is based on three factors, A that is the functions amplitude, ω is the frequency and θ is the phase.

$$A * \cos(\omega t + \theta) \tag{1}$$

We use the phasor by leaving out the frequency and will only carry on the amplitude and phase. This leaves us with the option to add the frequency factor to the array.

5.5.3 How the sound will be implemented in Pure Data

The way the sound will be implemented in pure data:

1. Input Sound
2. Array / Sample
3. Determine Sample Speed
4. Phasor
5. Merge Array and Sample Speed
6. Fliter (if required)
7. Output Sound

First step is to make sure that the sound will be imported into the program. Second step is to send the sound into an array that will split the sound into samples. The third step is to detect how fast the samples normally are going to be played in order to create the same sound. The fourth step is sending the sample speed into a Phasor. The fifth step is to merge the play speed from the phasor with the array with the samples. This will create the sound based on the play speed that has been changed. The sixth step is only to be implemented if a filter is required for the sound. The seventh and last step is the output sound that have been going through all the new changes and will now sound differently.

Now that all of sounds have been decided and the design of our product complete, we can now enter the implementation stage.

6 Implementation

Based upon the chosen design, a prototype will be developed. The prototype is separated into two parts: A visual representation of the weather data and an implementation of sonifications of the weather data.

6.1 Visual Implementation

As defined in the design chapter, visual representations of predefined weather data will be created.

The delimited weather data is:

- Temperature - Current air temperature 2 meters above terrain.
  - Day temperature
- Wind speed - Average wind speed over 10 minutes, 10 meters above terrain.
- Pollen Forecast - The potency of the pollen.
- Visibility - How far can you see with clear line of sight.
- Downpour - Rain in mm.

Furthermore, the visual pretest(See section 5.3) has helped define which specific visualisations of weather data that are to be created(See table 2. The results show the weather data along with descriptions of illustrations that should be implemented in each of the low, medium or high values of the different weather conditions.

Now that the visual pictures have been decided, the actual visualizations must be constructed. The following visualization represents our interpretation of the visual test results(See Appendix A.2), and will be used as the visual representation of weather data in the actual test (See figure 8).

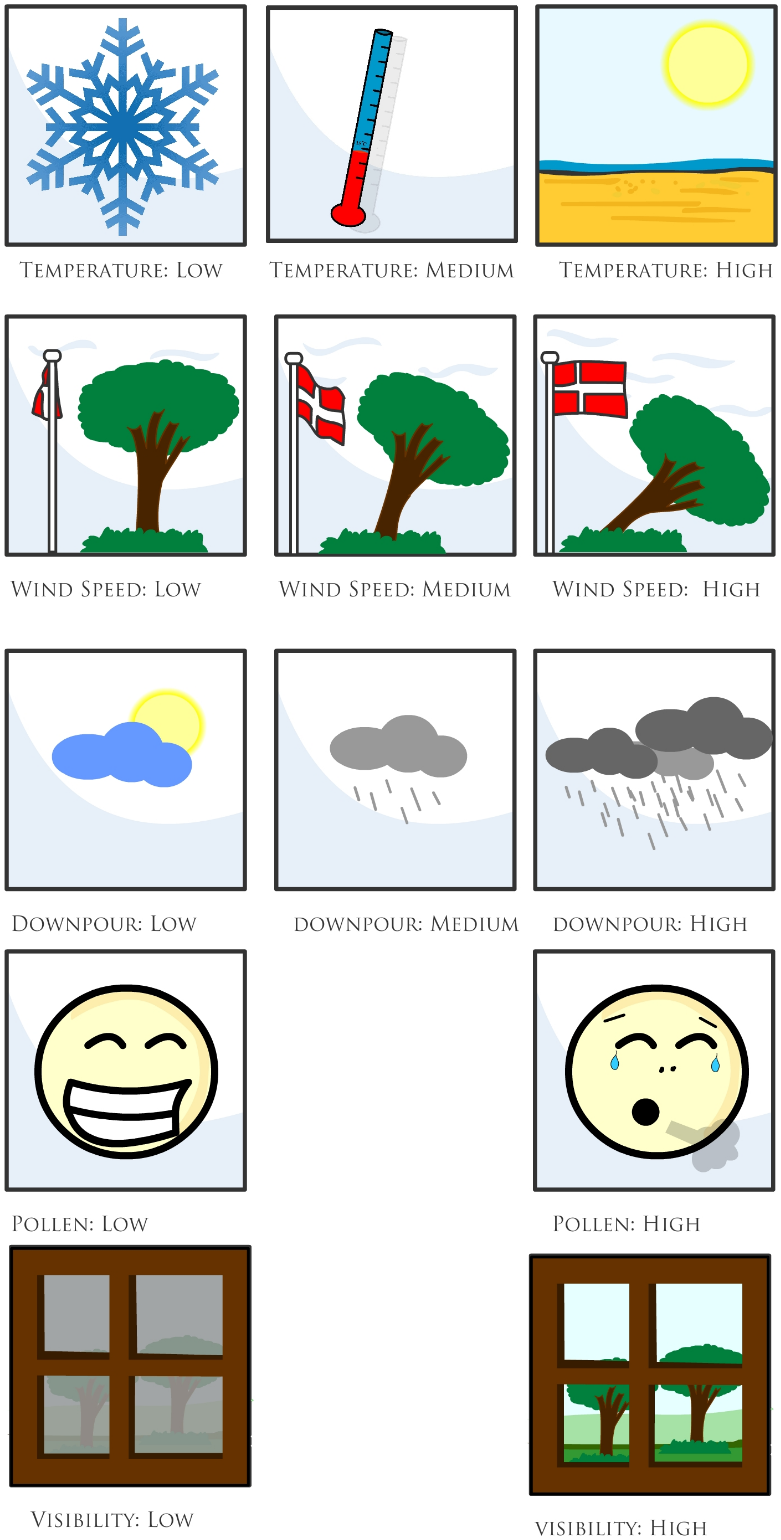


Figure 8: Visual implementation

6.2 Sound Implementation

As presented in the design (See section 5.5.3), the following list is defined as the procedure of the implementation of the sounds in PureData.

1. Input Sound
2. Array / Sample
3. Determine Sample Speed
4. Phasor
5. Merge Array and Sample Speed
6. Fliter (if required)
7. Output Sound
8. Tracker

Here is a overview of one of the pure data systems that has been made:

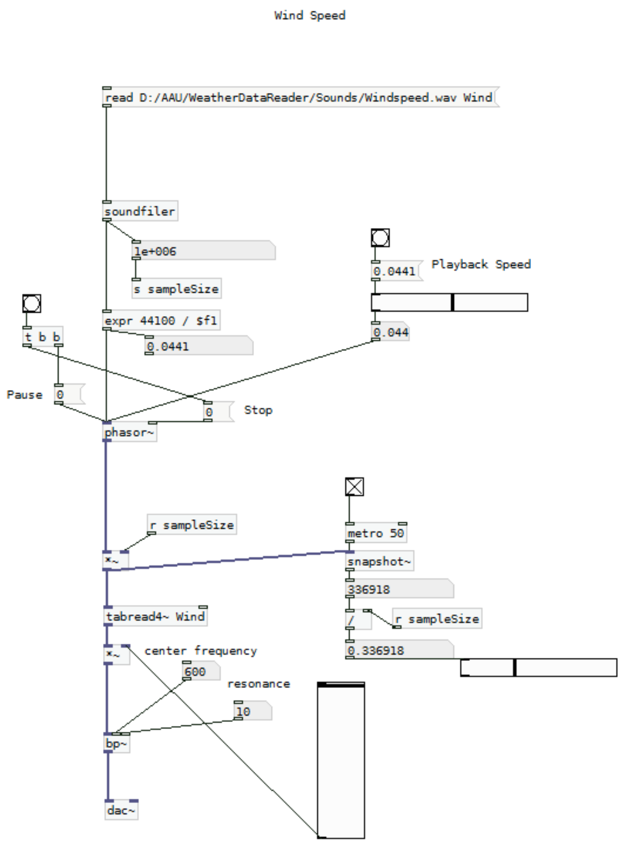


Figure 9: Sample Pure Data implementation

Step 1

Here the program reads where the sound is placed on the computer and imports it into an array. As seen on the figure 10 the path have been written down and in this case the array is called Wind.

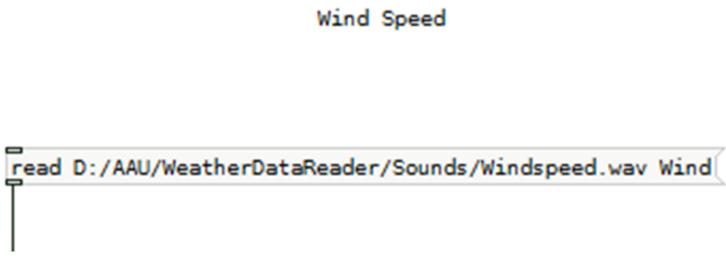


Figure 10: Sample audio import

This is the array itself (Figure 11). Here you can see what the different sound waves are going to look like. It might seem when you look at the arrays that there is a lot of wasted space in the array. This is simply because some of the sound don't last that long and the empty space you see in the array is less than a second when played.

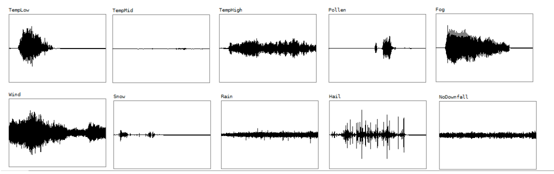


Figure 11: Sound sample array

Step 2

Here the soundfiler collects the amount of samples and the speed. As seen on the picture (Figure 12) the sample amount is been read and stored in sampleSize which will be used later in the program. The data follows the path down to the phasor.

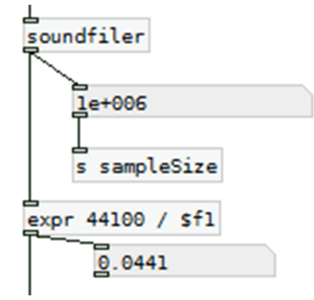


Figure 12: Soundfiler implementation

Step 3

We made a system that can control the speed of the samples. Using this, we can replace the original speed with our own to change the playback speed of the sound. This is using the custom made slider right besides the text Playback Speed on the picture (Figure 13).

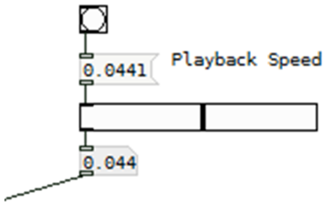


Figure 13: Playback speep sample

Step 4

All the information sent to the phasor that carries the new information over to the next step which merges with the array.

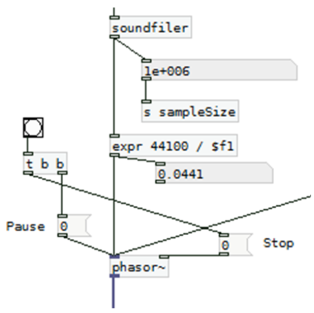


Figure 14: Phasor

Step 5

Here (Figure 15) it loads the old array with the new changes to the sound. At this point the play speed has been changed and changes to the sound has been made.

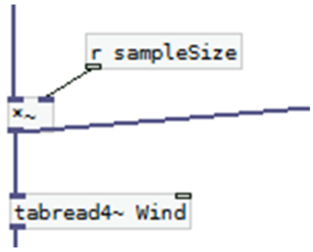


Figure 15: Load old array

Step 6

This is our bp̃filter as seen the two boxes linked to the filter are the center frequency and the resonance. In this case the center frequency is 600 and the resonance is 10.

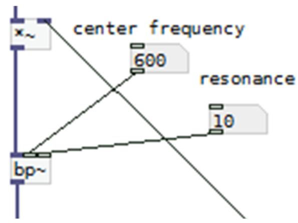


Figure 16: bp Fliter

Step 7

After the filter all the information is sent to dac̃which is the audio output.

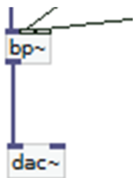


Figure 17: dac output

Step 8

Additional feature:

A length tracker was implemented in order to know when the sound clip was done playing. This doesn't change the sound output in any way but it's useful to know during testing.

Figure 18: Length Tracker

The rest of the sounds follow the same steps but the values is being replaced with these on our data sheet 4.

	Play Speed	BP-Filter
Pollen	High: 0.418208	N/A
Visibility	Low: 0.382	N/A
Temperature	Low: 0.8339 Mid: 0.0441 High: 0.0882	N/A
Downpour	Low: 0.06 Mid: 0.2205 High: 0.37	N/A
Wind Speed	Low: 0.0441 Mid: 0.0441 High: 0.0441	Low: 300 - 10 Mid: 600 - 10 high: 900 - 10

Table 4: Data sheet

Now that the sounds have been implemented the product is ready for testing. This leads us into the next step in the process, the evaluation of our prototype.

7 Evaluation

The evaluation will be divided into three separate test scenarios. As we are looking into how we can convey weather data through sonification, and how intuitively understood this information compared to visual representations of similar data is. It will be possible to evaluate upon by isolating and comparing data from several tests, where one test is of the produced sonifications, another test with visual elements and one test where both visuals and sonifications is tested.

More specifically described, a test will be conducted solely where the weather sonifications are presented to test subjects. Similar, a test will be conducted where the visual representations will be presented with the same procedure as the sonification, and finally a test where both visual representations along with the sonification of the data. This procedure will make it possible to compare what the test subjects can deduct from the presented data, and allow us to make comparisons towards what information the visual, sonification and combined representations of data is conveying, and thereby make it possible to evaluate upon how well the sonification formulate weather data.

7.1 Method

The primary reason of the evaluation is to establish knowledge as to determine if the list of requirements has been fulfilled and to make it possible to gain satisfying results which helps answering the final problem statement.

The implemented product contains sonifications of specific weather categories, where these categories has been further categorised into sonifications of different values which represent low, medium and high values of a specific weather category.

A Kruskal-Wallis test will be conducted on the gathered test results, which will be separated into three separate tests. This will ensure that it is possible to distinguish between the results gathered from the low values, medium values and the high values of the weather data, and will provide 3 seperate box plots and associated data, which will allow us to prove or disprove the null hypothesis and to make assumptions and further analysis which will help answering the final problem statement.

7.2 Procedure

Here are the procedure for the test explained in detail. This chapter will describe the different aspects of the test such as sampling, observations, and guidelines for the testing. The same test procedure will be done on three separate presentations of weather conditions: visual presentation, audial representation, and combined presentation. The general data for the tests are presented below.

Amount of participants: 20 subjects per category per presentation. Test subject sampling: Convenience sampling: Aalborg university students. Estimated length of test: 1 minute per subject. Test location: Area on and around Aalborg university. Date and time: When appropriate.

7.2.1 Test setup

The test will not require any specific location. For the testing only two people are present, i.e. 1 test subject and the test conductor. Only the combined test required two conductors for convenience purposes. The test subject and observer will be placed opposite each other during the test. Other individuals, in this case other test subjects, will be placed out of view to avoid bias by previous subjects answers.

7.2.2 Test Materials

Visual test

- Visual samples: A set of images each representing a separate weather condition. The samples will be be presented to the subject one at a time to avoid that the subject makes assumptions based on the other samples.
- Notation sheets: Sheets of paper where the presented samples and respective responses are recorded.

Sound test

- Audio samples: A set of audio snippets each representing a separate weather condition. The samples will be produced on scene using Pure Data and will not be prerecorded.

- Notation sheets: Sheets of paper where the presented samples and respective responses are recorded.

Combined test

- Visual samples: The same samples from the visual test.
- Audio samples: the same samples from the audial test.
- Notation sheets.

7.2.3 Test Execution

The testing procedure differs slightly in the three tests. In the visual test the subject is presented an image of a weather condition. The images does not contain the actual weather data they try to represent. During the audio test the subject is presented with an audio sample produced by Pure Data, and in the combined test the subject is presented with both an image and an audio sample of the same weather condition.

The overall testing execution looks like this:

- The subject is placed opposite the observer.
- The observer presents the subject with a sample. The samples does not have to be in any kind of order because the subject has no knowledge of the different weather conditions that will be presented.
- The presented sample is noted by the observer and the observer ask the subject if the if the sample presents a low, medium, or high value.
- The observer notes the answer and continues to the next sample until a sample from each category has been answered.

Before each test the subjects are informed that they are to be presented with 5 different samples (one for each category). They will be asked a question to each sample and that they are only to answer "high", "medium", or "low" to the questions. In order to ensure that each subject has the same understanding of the samples they are given some context for each sample. This is done through the question asked to each sample. The question contains the weather condition but not the actual data i.e. "How much wind is in this image, high, medium, or low?". The subject will not be given any further clarification as we are looking for the intuitive guess and not the qualified guess.

7.3 Hypothesis

Based upon the formulation of the final problem statement, the scientific experiment can be deducted into two separate hypotheses. One hypothesis which specifies that there are no significant difference between the samples, and one hypothesis which specifies that there is some significant difference.

7.3.1 Null Hypothesis

There is no significant difference between the understanding of the non-speech auditory display of weather data using sonification techniques, compared to the understanding of visually presented weather information.

7.3.2 Alternative Hypothesis

There is some significant difference between the understanding of the non-speech auditory display of weather data using sonification techniques, compared to the understanding of visually presented weather information.

7.3.3 Test Delimitation

In order to prove or disprove the Null hypothesis, a statistical test is specified. The method of establishing knowledge towards what test will be used, the structure from Andy Field & Graham Hole is utilized **Field2003**

7.3.4 Type of data that is collected

The data that is collected from the test participants is considered scores. As we are collecting data through a scientific study, the data that is contributed from the test participants are nominal data, being data that uses numbers to define categories or range of values which the test subjects think is correct.

What is obtained from the test participants is a value from 1-3 indicating low, medium or high values of a specific weather condition, which indicates their intuitive thought of what the formulated weather data represents.

7.3.5 Independent variables

Independent variables, being something that is manipulated by us, is the weather conditions. There are one independent variable in this study, being the specific formulation of a single weather condition. As an example, the test subjects are presented with low/little rain as a visual image. Other test subjects are also presented with low/little rain, but as a sonification, or both. Then the test subjects provide scores, indicating what they actually think is presented.

7.3.6 Experiment design

As we are looking for differences or similarities between groups of which we have altered independent variables, an experimental design is utilized.

7.3.7 Independent measures

Since we look for intuitively understanding of a sonification of weather data, each participant will only be subjected to one condition of the test. This will allow us to obtain a single score from each participant in either the sonification, visual, or sonification & visual test. The study can therefore be described as a wholly independent measure design test.

The test subjects will be allowed to contribute with several answers within the same condition, but will not be allowed to contribute to others.

7.3.8 Non-parametric

As we have no pre-defined assumptions to the test, and to what extent there might be certain characteristics, the study can be described as non-parametric.

7.3.9 Test groups

As specified as the independent variable, there are three different groups which contributed with scores.

7.3.10 Kruskal-Wallis Test

By delimitating the above mentioned steps, it is defined that a Kruskal-Wallis test can be utilized to prove or disprove the Null hypothesis.

A Kruskal-Wallis test compares between the medians of two or more samples, to determine if the samples have come from different populations **Gaten2000**

There are however, the following limitations to the Kruskal-Wallis test. If no significant difference in our data is found, the samples can not be concluded as to being similar. If there are any significant difference, it is not possible to make specific assumptions as towards what contributed to the significant difference. Further analysis and testing would be required **Gaten2000**

7.4 Results

The results from the test are here presented and described. Discussions and interpretations of the results are conducted in the Evaluation: Discussion (See next section XX)

The gathered results can be found in appendix (XX).

1 2

Low: Visual Elements																					
Temperature	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Rain	1	1	1	1	1	1	1	2	1	2	1	1	1	2	2	2	1	2	1	2	
Wind Speed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Visibility	1	1	1	2	2	2	2	2	2	2	1	1	1	1	2	2	2	2	1	2	Inverse
pollen	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	2	1	1	1	3	

Medium: Visual Elements																					
Temperature	2	2	1	2	1	2	1	3	1	1	1	1	1	1	2	1	1	1	1	1	
Rain	1	1	1	2	2	2	2	2	2	2	2	2	2	3	2	1	1	2	1	1	
Wind Speed	2	3	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	
Visibility																					Inverse
pollen																					

High: Visual Elements																					
Temperature	3	3	2	3	3	2	3	3	3	3	3	2	2	3	3	3	3	2	3	3	
Rain	3	3	2	2	2	3	3	2	2	2	2	2	3	3	3	2	3	3	2	3	
Wind Speed	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	
Visibility	2	2	2	2	3	2	3	3	2	2	2	3	3	2	3	3	2	3	3	3	Inverse
pollen	3	3	3	3	3	3	3	3	2	3	2	2	3	3	3	3	3	3	3	3	

Figure 19: Test result snippet

As seen on figure 19, there are three categories. Low elements, medium elements, and high elements. This example only covers the visual weather data. The results gathered from Sonification, and sonification & Visual elements can be found in the appendix(XX).

The numbers indicates the responses from 20 test participants. These are labels of 1-2-3 which indicates low, medium and high values.

The rows indicates responses from a single test participant.

- Low values has the label: 1
- Medium values has the label: 2
- High values has the label: 3

It can be deducted from the figure, that if a low weather condition which has been answered and labeled with 1, then the answer is correct, as the image illustrates a weather condition of low value. Likewise with medium values which has the answer of 2 and high values with the answer of 3. If a medium sound is heard, and the test subject answers correctly with a response of medium, then 2 is noted.

7.4.1 Kruskal-Wallis Test Results

The test results will be divided into three separate Kruskal-Wallis tests, in order to evaluate upon low data, medium data and high data separately, to make the distinction between the independent variable more easily. What will be the outcome is a Box-plot, respectively of low, medium and high weather data elements along with the data descriptions of the three Kruskal-Wallis tests.

Low values: Kruskal-Wallis ANOVA table

The P value(Prob>Chi-sq) is 0.0042 which is under 0.05. Therefore the null hypothesis is rejected and accept the alternative hypothesis.

Low values: Kruskal-Wallis test results

Generally the boxplot indicates similar levels of medians but the visual scale has a different distribution than "Sound and Visual" and "Sounds".

The "Visual" element is comparatively short, as the inner quartile range is overlapping which suggests that a high number of responses are 1. A majority of participants answered correctly, but a low number of participants, indicated by the "plus", that 2 and 3 was also answered by a lower population of the test participants.

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Columns	53754.2	2	26877.1	10.95	0.0042
Error	1414250.8	297	4761.8		
Total	1468005	299			

Figure 20: ANOVA table low data

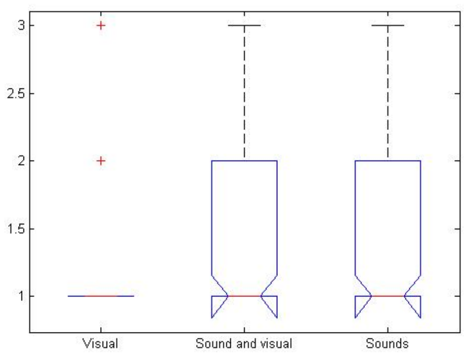


Figure 21: Boxplot low data

7.4.2 Graphical test results

As the Kruskal-Wallis test only provides knowledge of statistical differences of the data groups, it is also important to gain knowledge of the specific weather condition elements which proved to be successful or unsuccessful. In order to elaborate upon what sounds, compared to the visual elements had any/if any specific impact. Therefore a graphical structure of the results are developed. (Appendix XX)

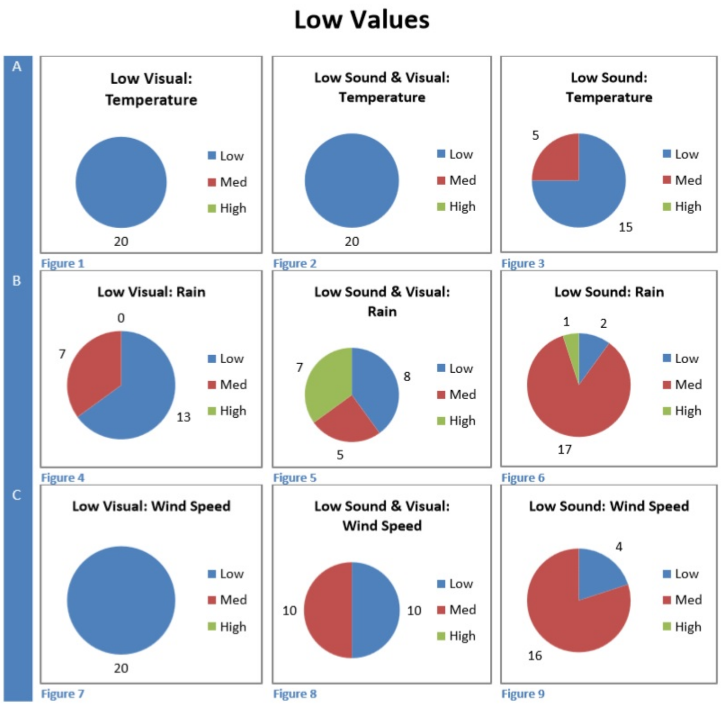


Figure 22: Snippet of graphic chart: Test Results

As seen on figure 22, a snippet of the pie charts are presented. On the row A1-3, the three temperature results is comparable. The pie charts each represents 20 responses and indicates the participants answers of the visual elements, sound and visual elements and the sound element. See(Appendix XX.) for the combined graphical results.

7.5 Discussion

Here, the discussion and interpretations of the results are presented. What is deducted from the data and what thoughts as towards what the answers indicate will be described and explained.

The figures(20, 23 & 24) indicates the ANOVA tables of each of the Kruskal-Wallis tests which were performed on the low, medium and high weather data conditions.

Low Value ANOVA Table

The P. value(Prob>Chi-sq) is 0.0042 and is below 0.05 as it is our Confidence Interval, which then indicates that the null hypothesis is rejected, and that the alternative hypothesis is accepted.

This indicates that there is some significant difference between the understanding of the non-speech auditory display of weather data using sonification techniques, compared to the understanding of visually presented weather information specifically for specifically low value weather conditions.

Middle Value ANOVA Table

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Columns	20042.3	2	10021.2	9.46	0.0088
Error	359345.2	177	2030.2		
Total	379387.5	179			

Figure 23: ANOVA table medium data

The P. value(Prob>Chi-sq) is 0.0088 and is below 0.05 similar to the above mentioned P value, where the Null hypothesis therefore also is rejected with the middle value test results.

High Value ANOVA Table

The P. value(Prob>Chi-sq) is 0.0561 and is above 0.05 then indicates that we fail to reject the null hypothesis with specifically high value weather condition results.

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Columns	21880.5	2	10940.3	5.76	0.0561
Error	1113847.5	297	3750.3		
Total	1135728	299			

Figure 24: ANOVA table high data

There is no significant difference between the understanding of the non-speech auditory display of weather data using sonification techniques, compared to the understanding of visually presented weather information specifically for high value weather conditions.

Yet we cannot state that the samples are the same. Further elaboration will follow.

7.6 Kruskal-Wallis tests Boxplots

The low value boxplot (Figure 21) compliments the ANOVA table and illustrates significant difference of the independent variables between the visual, the sonification and both combined. We can see that a large amount of participants answered correctly on the visual test, but a few. And with the sound and sound & visual, the upper quartile indicates that from the median up to maximum, 50 % of test participants answered incorrectly, as the correct answer was 1, being the label of low whereof a large amount of the test participants answered 2 or 3. This indicates that a large amount of the test participants misinterpreted the sonification of low weather conditions.

The middle value Boxplot (Figure 25) indicates a difference in the visual, sonification and sound & sonification test results, which also has been defined as the alternative hypothesis has been accepted.

On all three groups, the median are 2, which is the correct label, middle value, and illustrates that a majority of the test participants answered correctly in each of the three tests.

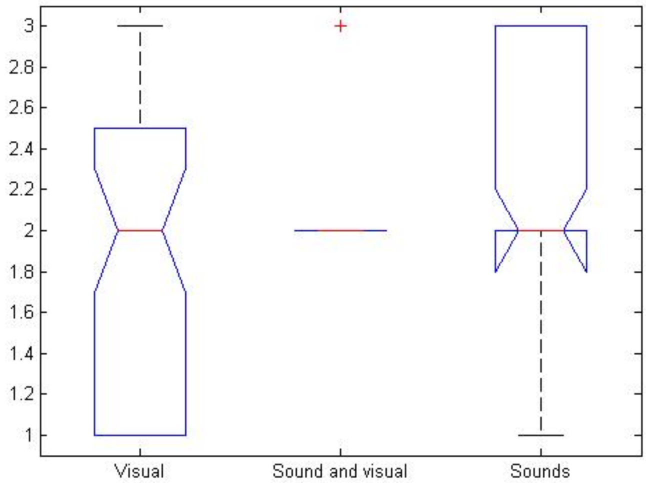


Figure 25: Boxplot medium data

The notched boxplot "Visual" illustrates that 50% of the test participants answered 1, which is incorrect and lower than the intended formulation. There are however below 25% who answered incorrectly in the test where Sound & Visual was presented, and only 3 (high value) was answered as a wrong answer by a small number of the test participants.

Lastly the boxplot of sounds indicate that a majority answered correctly with 2, but 25% answered 3, and another percentage of test subjects answered 1, which indicates that there are a majority of test subjects which misinterpreted the middle value sonifications.

The High-value boxplot of which the null hypothesis is accepted, there are no significant difference in the samples. They are however not similar. The Visual sample indicates that 25% of the test subjects thought of some or more of the visual interpretations of weather conditions as being a middle value.

There are however in the sound and visual sample below 25% who thought that is was a medium value. And with the sound sample, below 25% of the test participants thought that the sonification indicated either low or medium, leaving 75% test participants answering correctly.

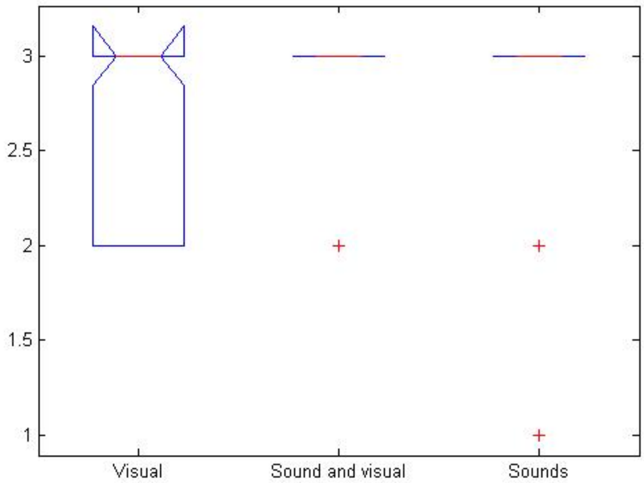


Figure 26: Boxplot high data

7.7 Pie charts

Although the boxplot and ANOVA tables indicates any similarities or differences between the samples, they do not describe what specific sounds/visuals which had any impact or what could have been done differently or what specific sounds which were actually successful in conveyance of sonifications of weather data. However, the following appendix(XX: Pie chart appendix)) indicates the percentage of correct responses of each weather category, and makes it possible for comparisons.

8 Discussion

In this chapter the project will be discussed and reflected upon. This includes insight as to what could have been done differently to improve the acquired results, or and what impact any decision throughout the report might have had. Ultimately the discussion will lead to how the problem statement can be answered i.e. how well the problem was solved, and what this result implies.

For the visual part of our test, (See chapter 5.3) we conducted the test using images created by ourselves, based upon the visual pre test, which could have changed/affected the test results. We chose to create our own pictures since we believed it would not matter if they were taken from a website or drawn by us. We based our drawings on information given from the visual pre-test . The test results indicates that not everyone could see what the pictures represented(See appendix C.2) This is of course an issue and for further testing these images should perhaps be replaced with something not based on our pre-test, but pictures found on weather represented websites or authored by a professional. Pictures as these may be more recognizable for people since there's a chance they have seen them in weather forecasts on TV or in newspapers, which could in turn lead to different test results.

Something that might have made a difference to our test results is the implemented filters. The idea of changing some aspects in the sounds might not have worked out as well as we had hoped. From our observations during testing, we observed that even though we changed some of the sound it still sounded the same for the testers. An example of this is that our rain sound might sound similar at the medium and high values. This is most likely because they never heard the other sounds for the two other values, so they had nothing to mentally compare with. It was also not possible to make it sound like there was close to no rain, without making it sound unnatural. We believe that it could be more efficient to have different sounds instead of changing one sound to represent the different weather data values.

In the design (See section 5.2.1) it was delimitated that the range of weather condition data should not be sonified in a continuous manner, where every value had a sonification, but rather in sections which were represented by low, medium, or high values in which the specific weather condition was implied which was described as event based sonifications. By making the decision of delimitating the amount of sonifications, and altering the sonifications from exact values to an indication of a specific range of values formulated by a label of low, medium, or high where the understanding is individual to each test subject, the sonification itself is altered to formulate another type of content, rather than the actual weather data.

What this implies is that we make a predetermined decision towards the possibility of making an exact sonification of the entire ranges of values in a specific weather condition, and to be intuitively understandable, which we believe to be impossible.

The obtained test results have both positive and negative indications regarding the success of intuitively understanding the visual and sonified weather data, but the data only represents low, medium, and high values, where a continuous sonifications of weather data should indicate degrees, wind speed etc. where decimals are included, if it was to be an exact interpretation of the designated set of data.

In the analysis chapter (See chapter 3.1.1), an example is provided where a similar procedure was used. In this example it is stated that engineers had to repeatedly listen to the different predefined values for a while, before being familiar enough with the sound to understand what it meant. This is unlike the intuitive sonifications which a user should be able to understand without having to learn what data the sonification implies.

The evaluation chapter in this report provides data from the test subjects that indicate differences or similarities in the data, when using the Kruskal-Wallis tests, and provides detailed information about specific weather condition data, which was correctly or incorrectly answered. See section (7.4) for evaluation results. However, there was not obtained test data, which elaborates upon why any of the presented weather data conditions were answered correctly or incorrectly, but we do have theories.

The pie charts (see appendix C.2) show the responses for each weather data information, indicated by a single pie chart in the appendix. The data does not specifically reflect the following , but we assume that weather conditions which actually have a sound are more likely to be intuitively understood than weather data which have no sound (but this is understood via associations). An example is Wind speed (See appendix C.2, K32). When there is wind, it is possible to hear the wind, unlike temperature. There is no sound of temperature, but associations that makes one think that there must be a specific temperature because of associated sounds. 100 percent of test participants answered correctly on high wind so a plausible solution can be that the sound is intuitive as there already exists specific sounds for wind. However, as indicated by low rain (Appendix C.2, B6), where there is a sound for low amount of rain, 17 out of 20 answered incorrectly even though rain ought to be intuitive much like wind speed. The reason for this error could however be our choice of sound representation which could indicate some other values. e.g. mid or high value of the data, leading the test subjects to answer incorrectly.

It can also be argued that associations to weather data is an individual interpretation, which makes it unlikely to make accurate sonifications of weather data, as there is no correct choice of sonifications to illustrate an association to the specific weather data, but only a plausible majority who may think that a specific sound/sonification accurately conveys that data.

While interpreting the results of the test, it became apparent that while it could be possible to evaluate upon each specific visualisation and sonification of the weather data, it would not result in any new information, which would allow for a more thorough and accurate answer to the final problem statement. This is because of the delimitation that has been made early in the design phase. The delimitation is the choice of only conducting sonifications of low, medium and high values. A re-design could be conducted where a questionnaire would be added to the predefined test structure where test subjects would be asked to describe what they think could be altered within the visualizations and sounds/sofications. This would give indications as to what could be altered in order to gain more accurate results, which would be reflected in the pie charts of each specific set of data values.

However, even if the test would be conducted and the sonifications and visualizations would be modified numerous times until the data from the tests would indicate that 100 percent of the test subjects answered correctly, the sonications are still delimited to low, medium and high values.

For this very reason it would seem unimportant to conduct further testing and re-design of the product. We would gain evidence to support the claim that it is possible to intuitively convey weather data, if the data is limited to low, medium and high values, but the test results is already indicating such assumptions to some extend whereof a number of test participants are answering correctly on each of the sonifications.

With what we have discussed so far, we can begin to discuss answering the final problem statement.

"To what extent is it possible to convey weather information, solely as a nonspeech auditory display, using sonification techniques, and be as intuitively understandable as visually presented weather information, where intuitive is defined as knowing by intuition?"

“To what extent...” is as mentioned defined by the choice of delimiting the continuous weather data values to labels of low, medium and high. We can therefore argue that it is indeed possible to convey weather information, solely as a nonspeech auditory display, using sonifications techniques, where the conveyed data is weather conditions with low, medium and high values.

The pretests (see chapter 5.3 and 5.4) indicates specific visualisations and sounds which could be utilized to the sonification of the data, which supports that the conveyed data is intuitive, meaning that a majority of the test participants could relate and understand the specific weather condition along with the specified data value, being low, medium or high. Also, as the results indicate, only a limited number of test participants answered correctly, but we assume that a refined product would make it possible to gain more satisfactory results, obtaining results that indicate a high margin of correctly answered questions within the low, medium and high labeled values of each weather condition.

Lastly, as we have also delimited the weather information, we can only account for the specified weather conditions as mentioned.

To elaborate upon the possibility of making sonifications to represent continuous values of a weather condition, in addition to the labels of low, medium and high, would require further testing, but we deem it possible.However, we question the usability, as the difficulty of conveying such small differences and changes would be very high. It would be very difficult for a person to either understand intuitively, remember, or even learn it in the first place.

9 Conclusion

Through the process of the project it became apparent that research areas such as sonification and weather data was obligatory to get an understanding of how it was possible, if possible, to convey weather information through sonification, as efficiently as visually presented weather data, which was deemed as the initial problem statement.

The analysis of the research lead to an understanding of knowledge of advantages and disadvantages of sonification along with sonification usage and state of the art of weather data presented using sound. Based upon this research it was possible to create a list of requirements which should suffice in the construction of a design that would aid in the answering of the final problem statement.

The test performed were build upon giving us the feedback needed for a Kruskal-Wallis test. This was done to see if there could be detected any difference between a visual represented weather forecast and an audio represented one, which was our sonifications based upon prior research in the design phase. The test were split into three sub tests (Visual , Audio, and a fusion of both aspects) that would provide three data sets that could be compared later and detect any differences. The data also provided pie charts to show each of the weather condition data elements with the distribution of answers.

The answers provide knowledge as to which sonifications were intuitively understood, and the acquired responses made it possible to answer the final problem statement.

We believe It is possible to convey the weather information that we have chosen to present to the test subjects, solely as a nonspeech auditory display, using sonification techniques. However, there is nothing in the test results that indicate that the sonifications are as intuitively understandable as the visually presented weather information. This is shown by the Kruskal-Wallis test, seeing as not all of the visual tests are similar to the results from the sonifications. Furthermore, the Kruskal-wallis test shows that the high value data was above the confidence interval of 0.05 and therefore shows that there is a difference between the visual representation and the sonification that represents the same data.

A statement, which has proven to be fitted on the obtained test results can be found in the pre-analysis (See Section 2,0); as Gregory Kramer writes: "The main problem is that it is difficult to provide adequate context for interpreting sonifications of data."

While the sonifications are defined by ranges of values being low, medium and high it is possible to make the sonifications intuitive. It would however be questionable if the weather data should be sonified as continuous data values that would represent any specific weather condition, as we deem it impossible to make intuitive, but the sheer development would be possible. We can therefore conclude that, with the chosen weather data, it is possible to convey the weather information through sonification. The extend of successful implementation of the sonifications are however limited by the choice of delimiting values to low, medium or high. More specific data content for the sonifications, and the success of such implementation would require additional research.

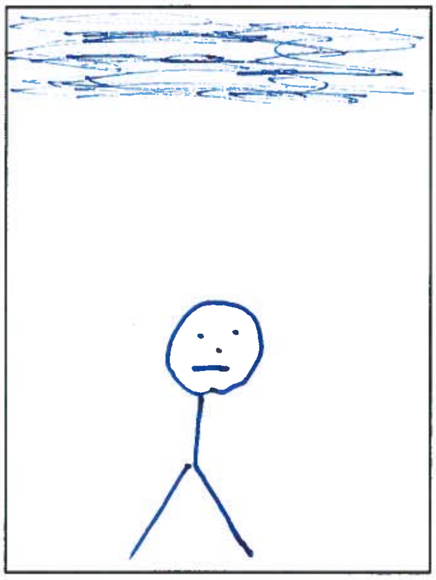
Appendices

A Visual Pre-test

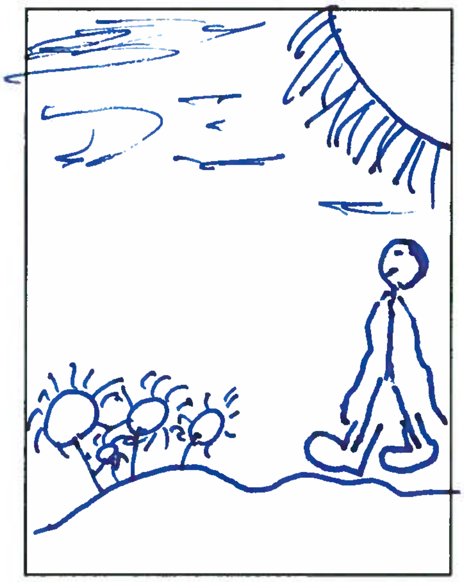
A.1 Raw Results

Nr. 23 Condition: Down pour

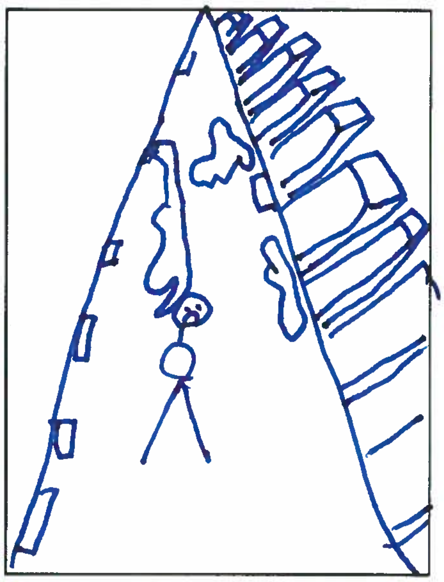
1



2



3



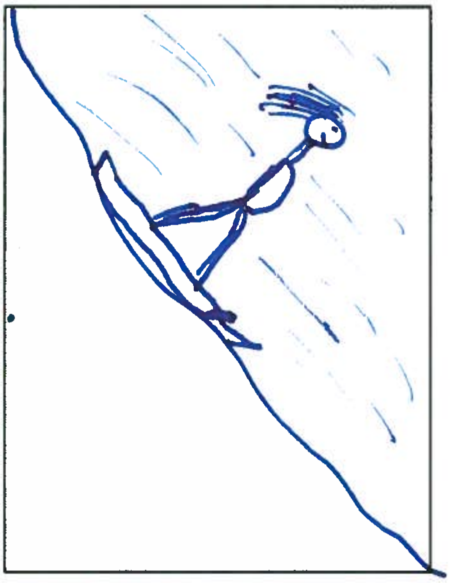
Skyet ligeglad person

Sol blomster mand i Regnslag

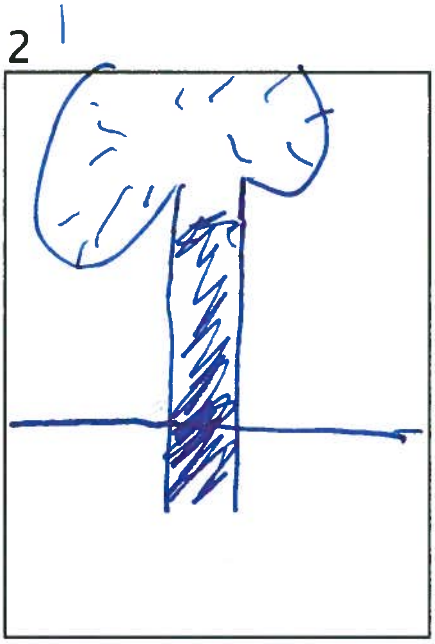
Sur mand Vand i by

Nr. 24 Condition: Pollen

1



2



3

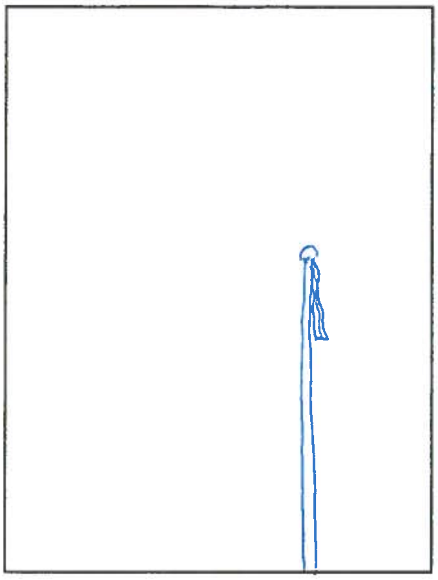
mand der står på Ski

træ

Snottet Storebror

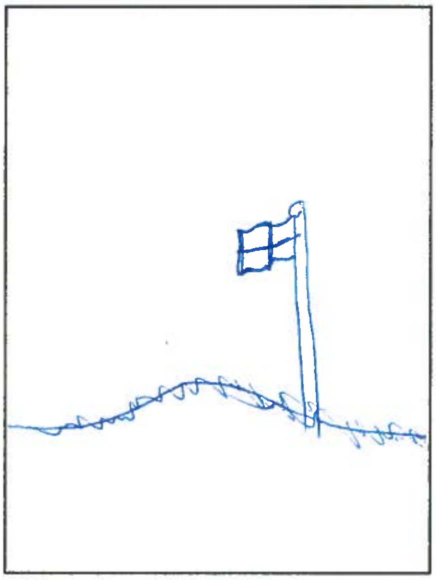
Nr. 2 Condition: wind

1



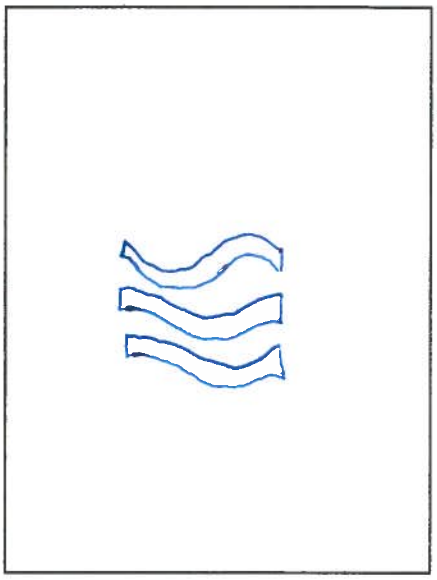
flag som hænger

2



blæst flagrene flag

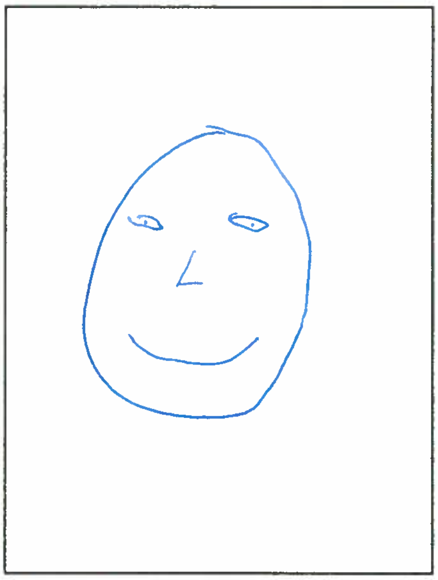
3



blæst "logo" ting

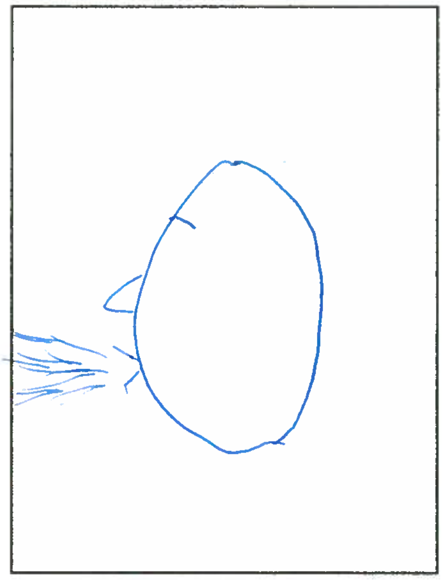
Nr. 4 Condition: Pollen

1



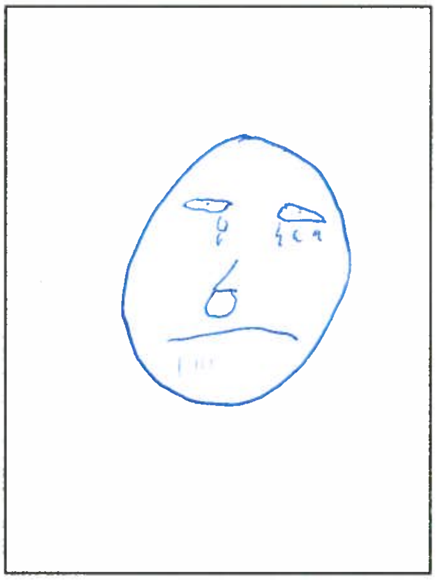
glad mand

2



achoo!

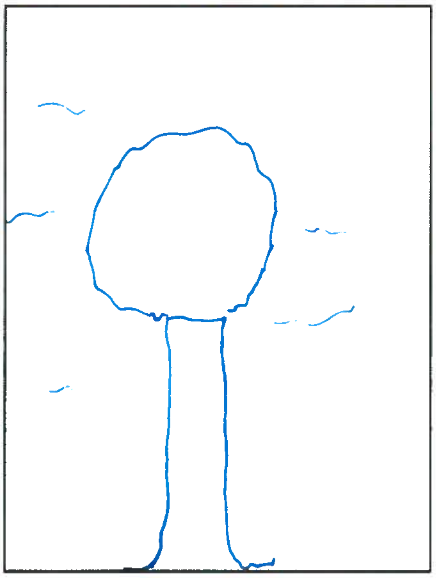
3



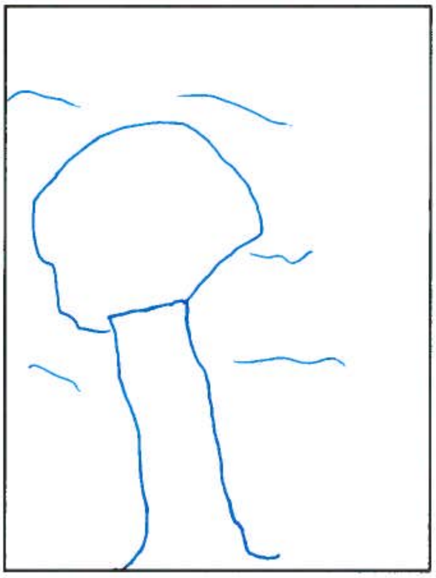
mand med væske ud af ansigt

Nr. 29 Condition: Wind Speed

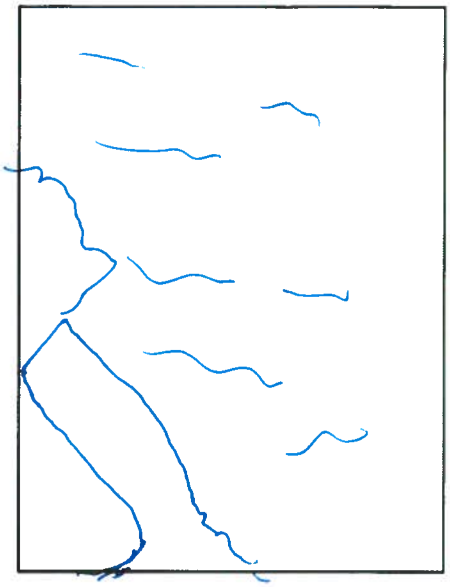
1



2

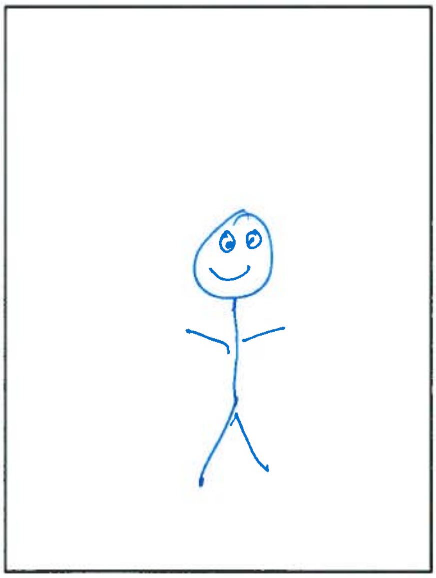


3



Nr. 30 Condition: Pollen

1

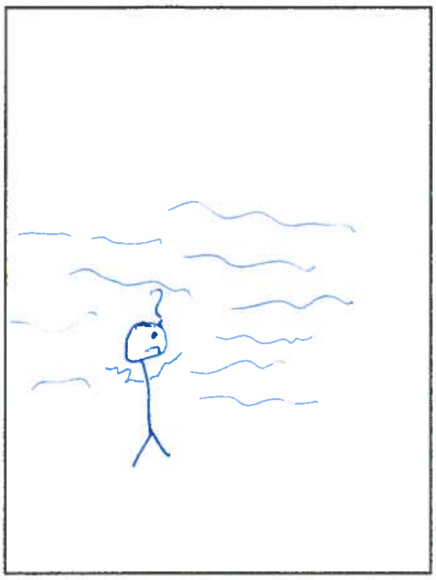


2

3

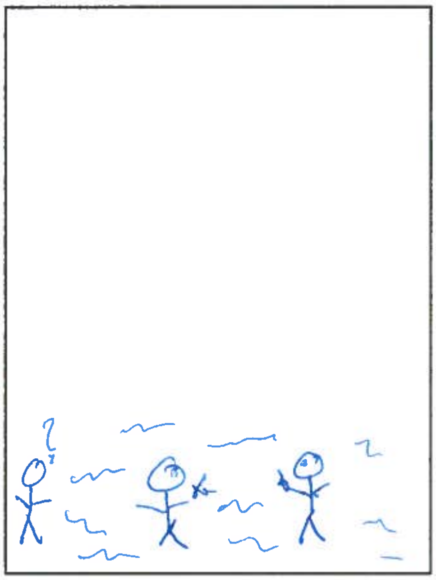
Nr. 5 Condition: visibility

1



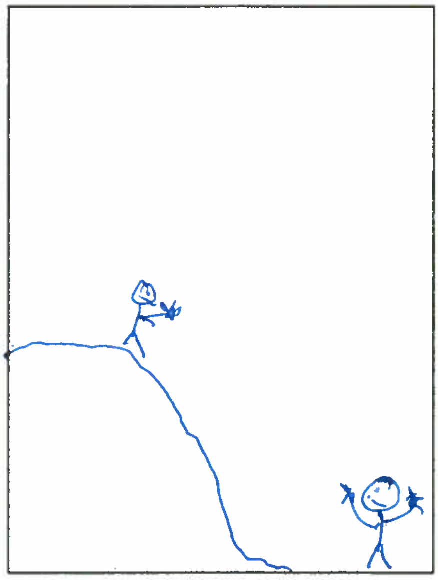
a man in the mist

2



only two people that see eachother

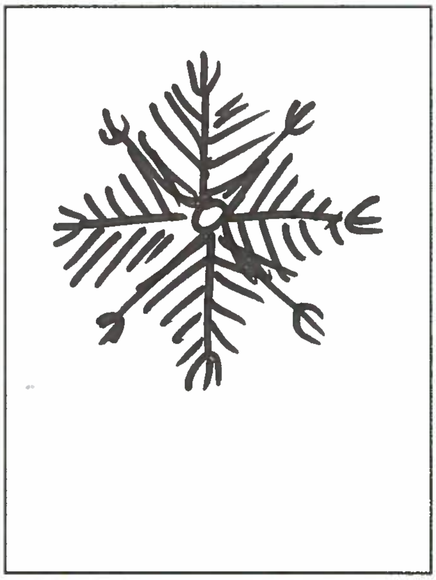
3



a man that waves to another man

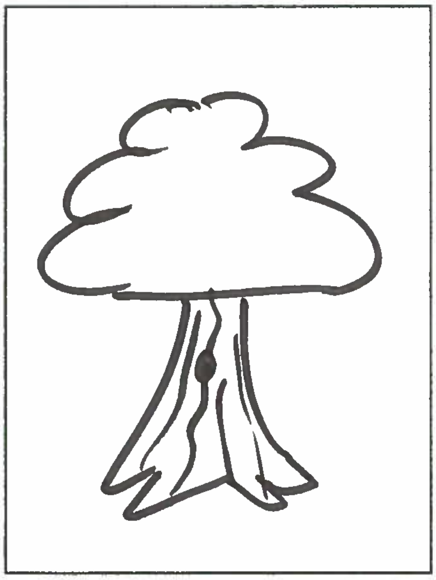
Nr. 6 Condition: Temperature

1



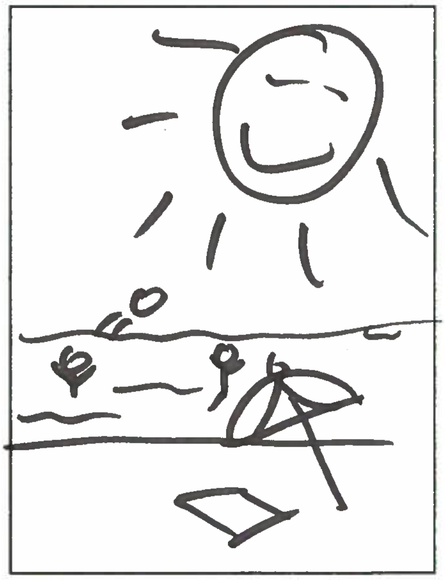
snowdrop

2



Tree

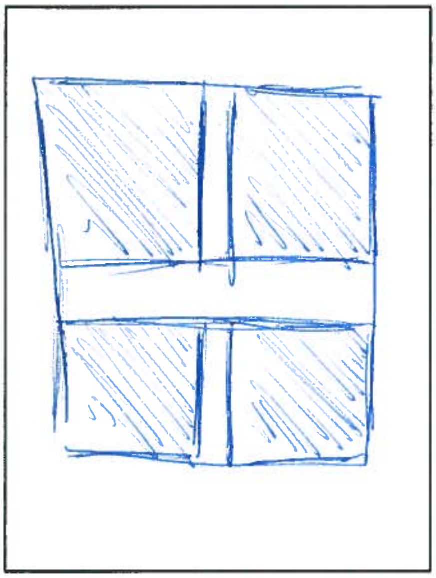
3



sunny day beach!

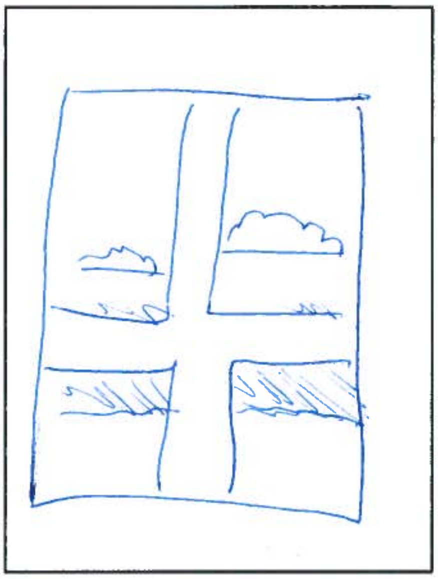
Nr. 33 Condition: Visibility

1



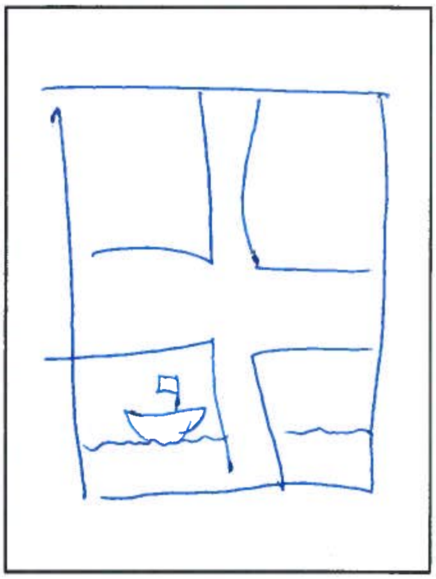
window - Gray outside

2



light gray with clouds

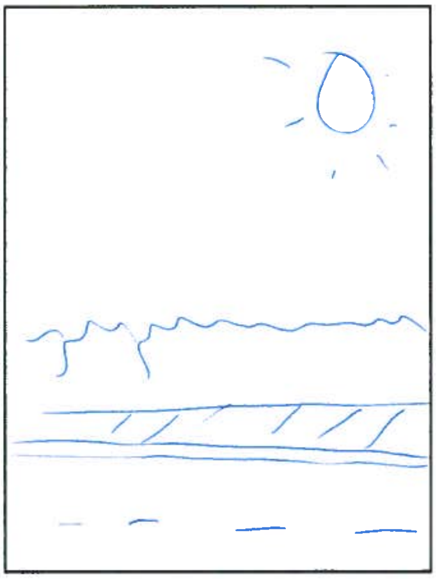
3



clear sky through window.

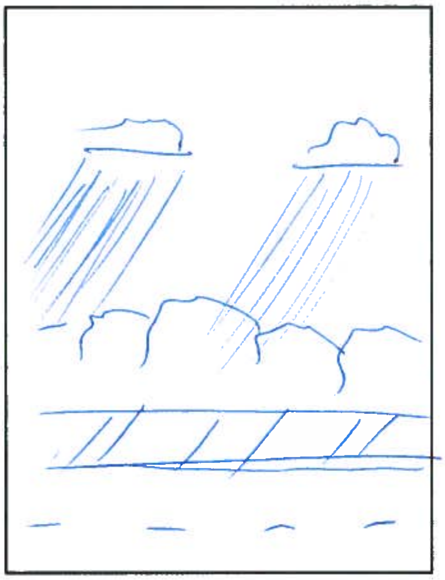
Nr. 34 Condition: DownPour

1



Dry day

2



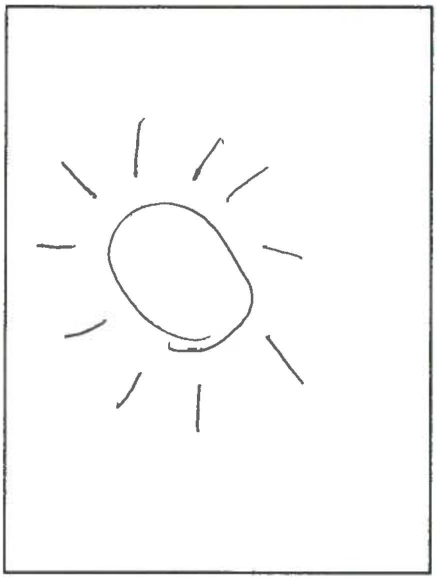
scattered rain

3

Powerful rain

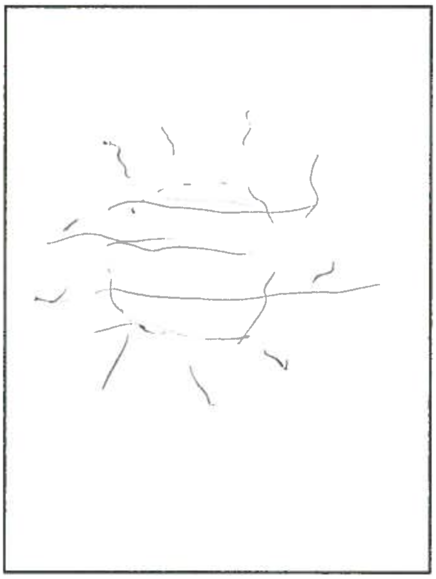
Nr. 11 Condition: Pollen

1



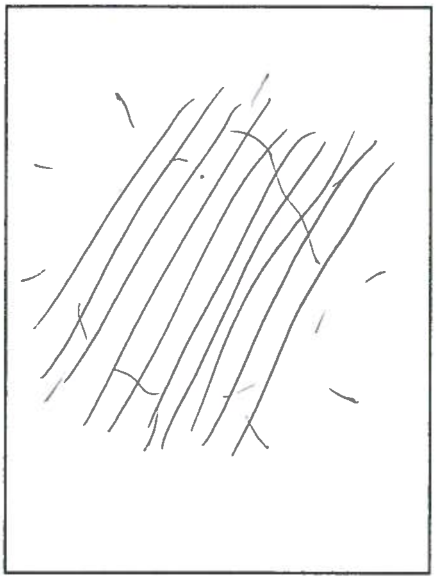
Sun

2



Foggy Sun

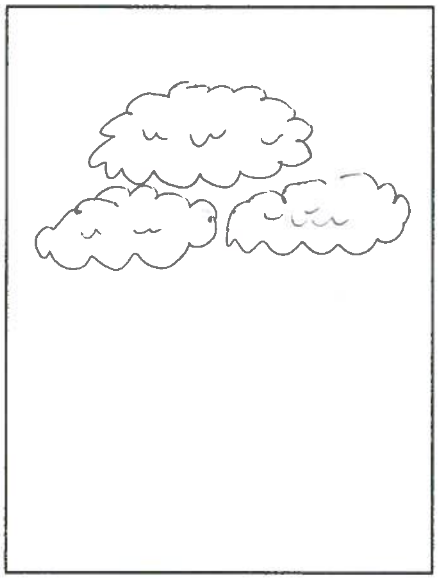
3



Covered Sun

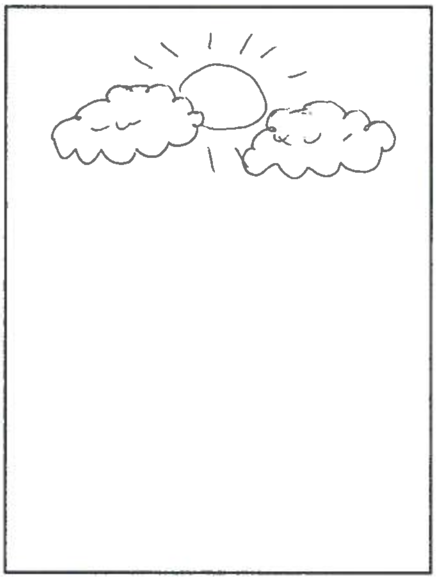
Nr. 12 Condition: Visibility

1



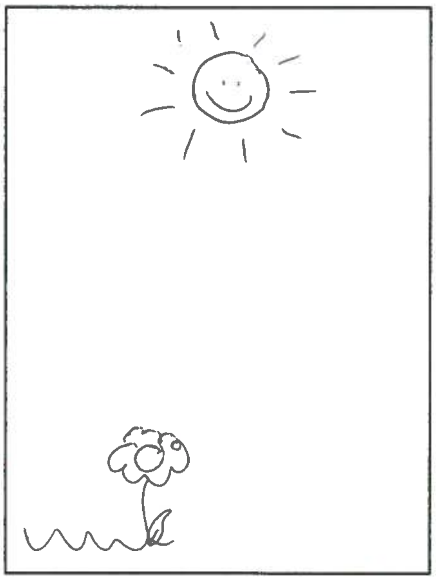
Low visibility= cloudy

2



More visibility less cloudy

3



Clear weather

Nr. 27 Condition: Temperature

1

2

Middel varm/let vind

3

Nr. 28 Condition: UV-Index

1

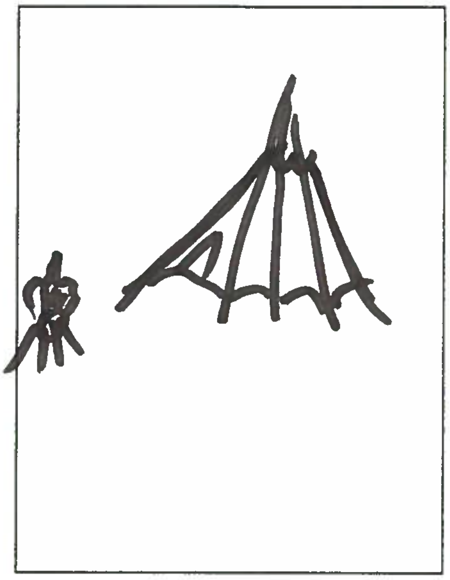
2

3

#DealWithIt

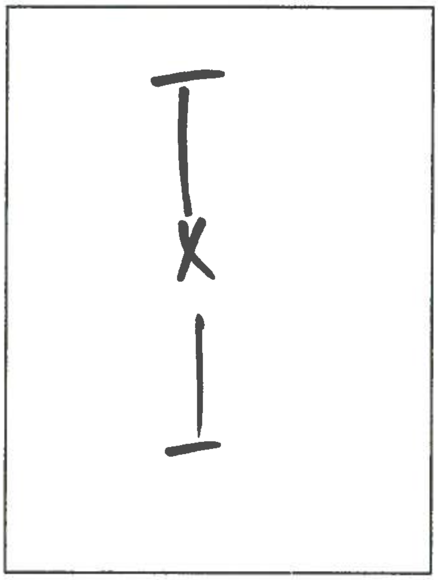
Nr. ~~6~~ 7 Condition: wind

1



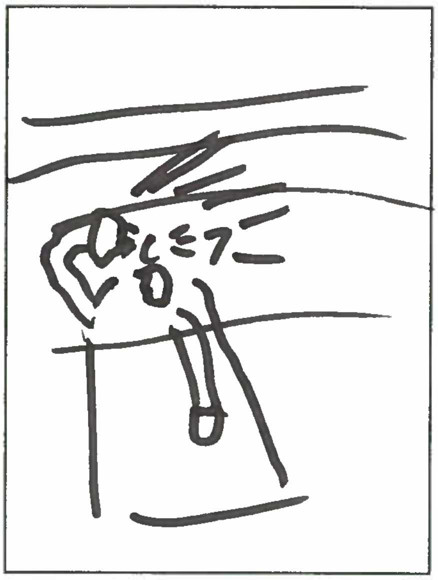
telt
bål

2



Middel

3



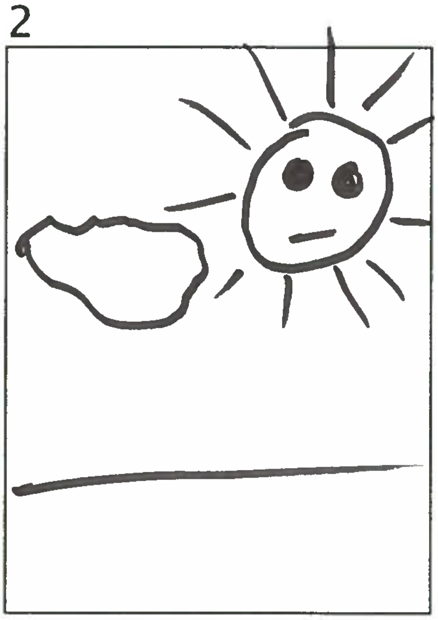
storm
vind

Nr. ~~7~~ 8 Condition: UV-Index

1

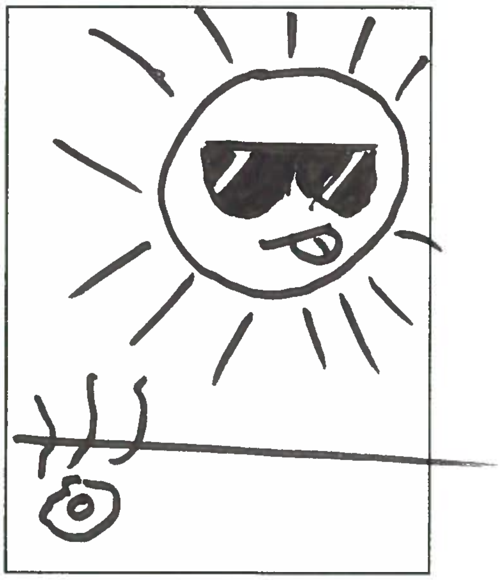
skyer foran solen

2



sol med en enkelt sky

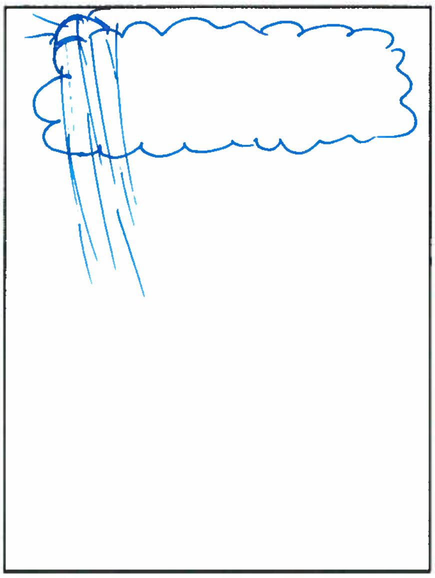
3



sol med solbrille og spejlæg

Nr. 21 Condition: UV-Index

1

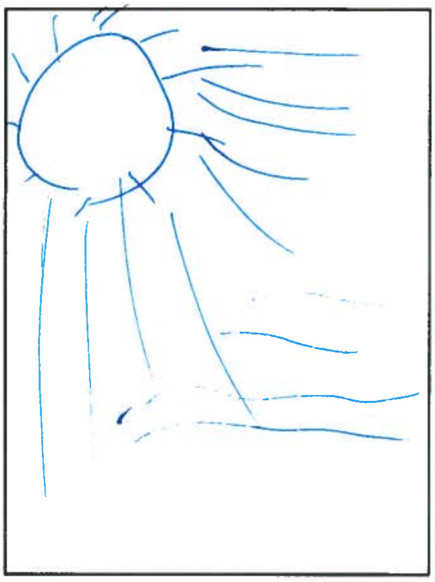


cloudy sky, a bit of sun

2

Some sun with some clouds

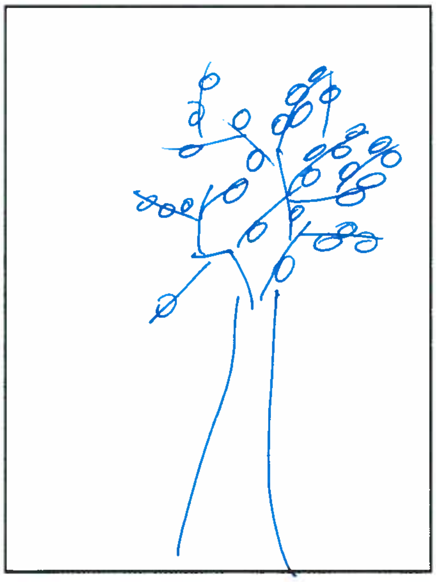
3



Full sun, heat waves in the air

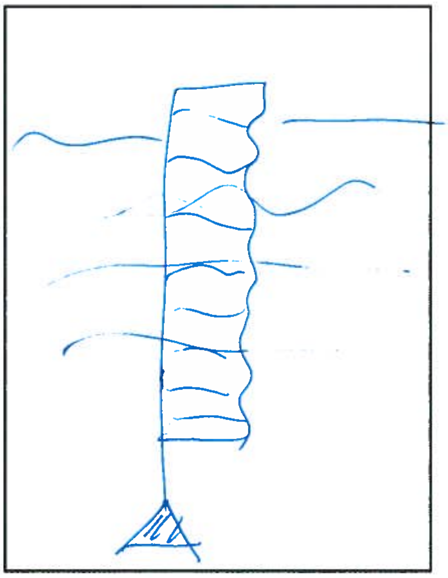
Nr. 22 Condition: Wind speed.

1



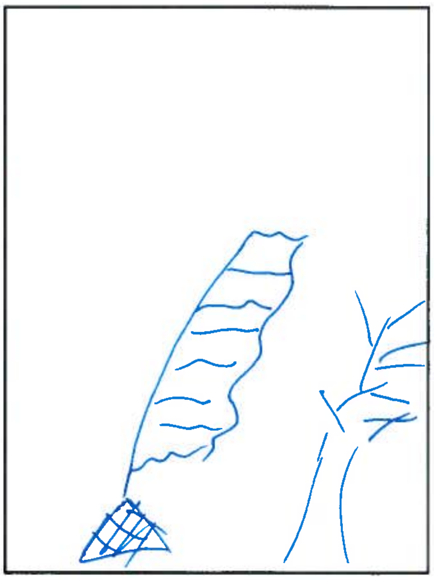
Tree that doesn't move at all

2



A flag moving with the wind

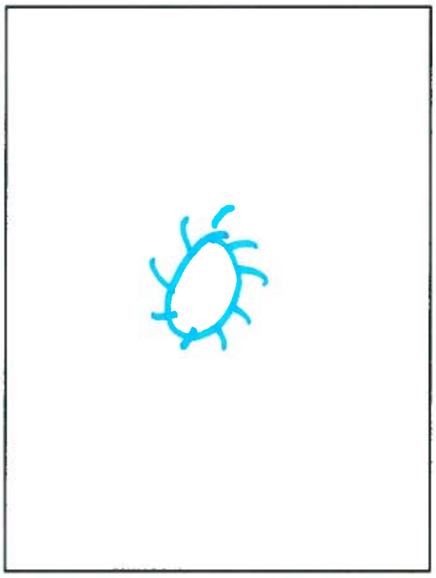
3



A tree and a flag bend from the wind!

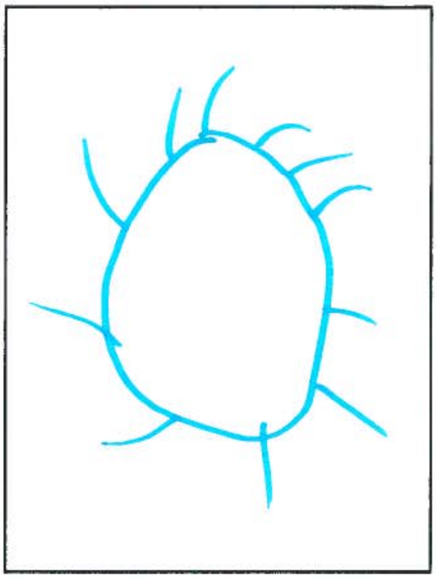
Nr. 31 Condition: UV-Index

1



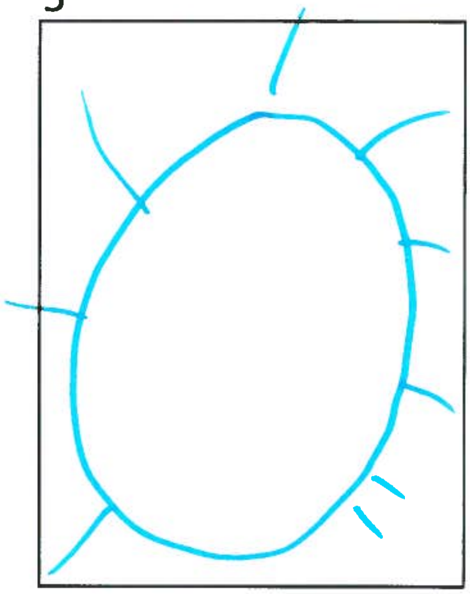
low sun

2



middle sun

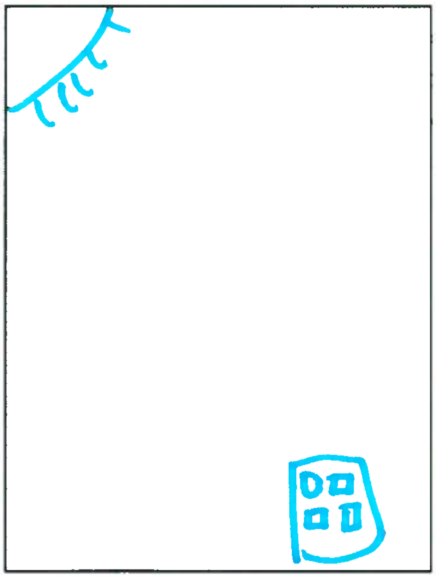
3



much sun

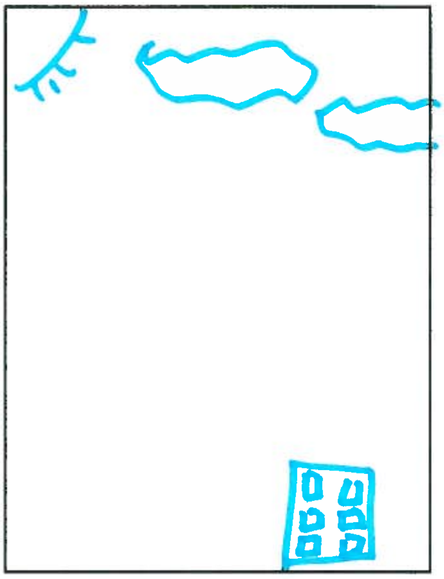
Nr. 32 Condition: Cloud Cover

1



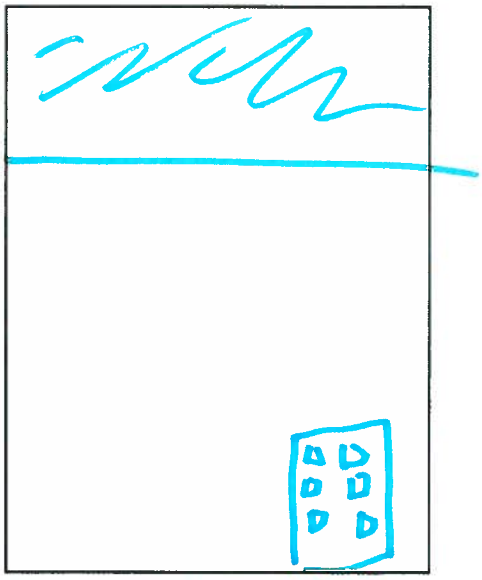
Clear sky over city

2



light clouds over
city

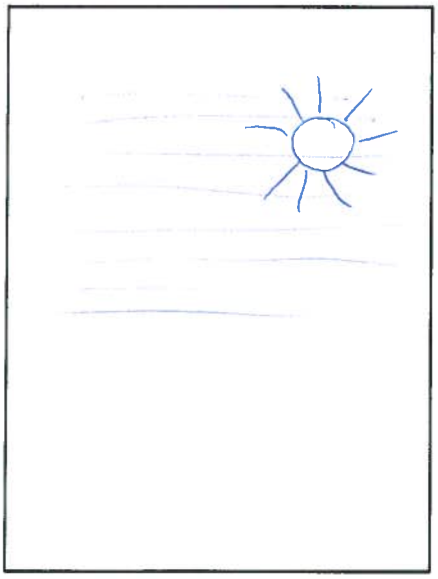
3



overcast over city

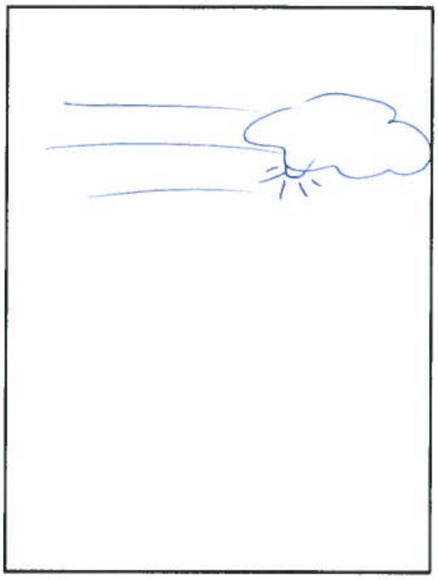
Nr. 13 Condition: cloud Com

1



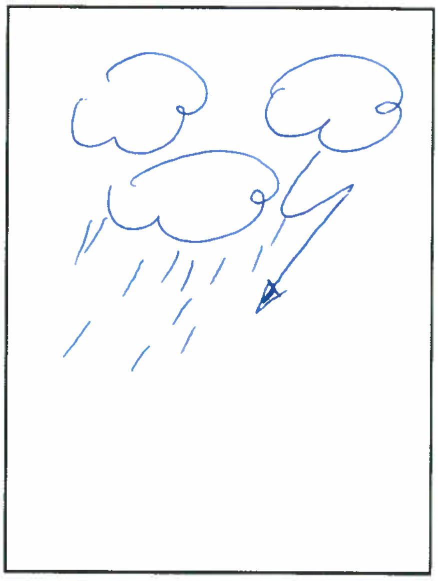
Sunny day, no clouds, yellow and blue

2



one cloud, a bit of Sun to get hope

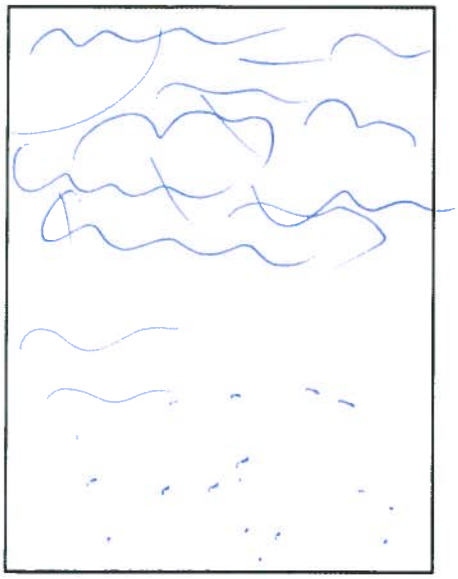
3



dark, dangerous

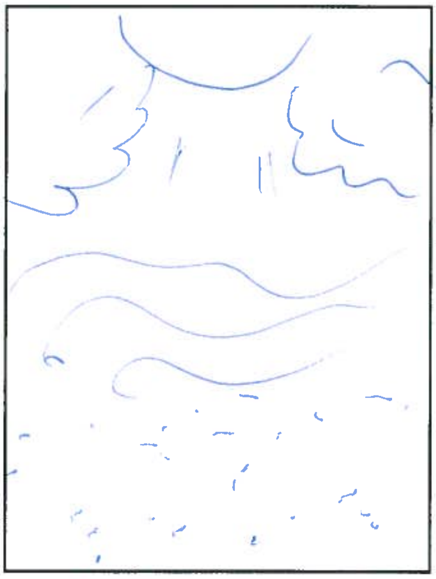
Nr. 14 Condition: UV-index

1



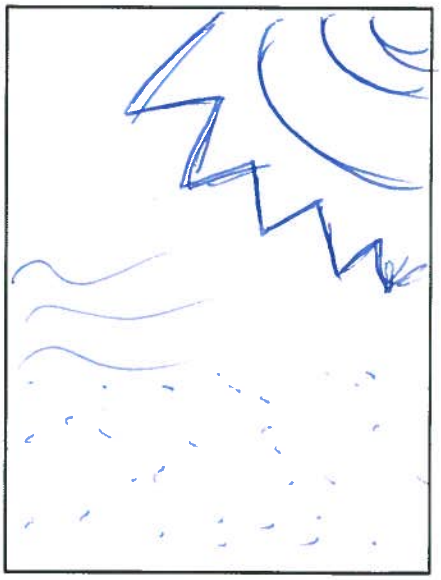
cloudy day at the beach

2



Pretty warm day, but cloudy though

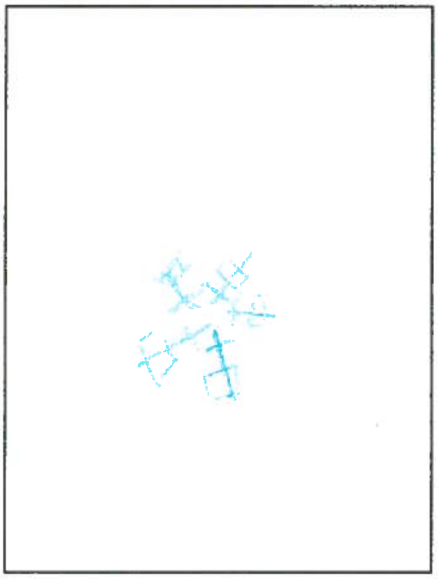
3



Sun, beach, very hot day

Nr. 1 Condition: Temp

1 0°

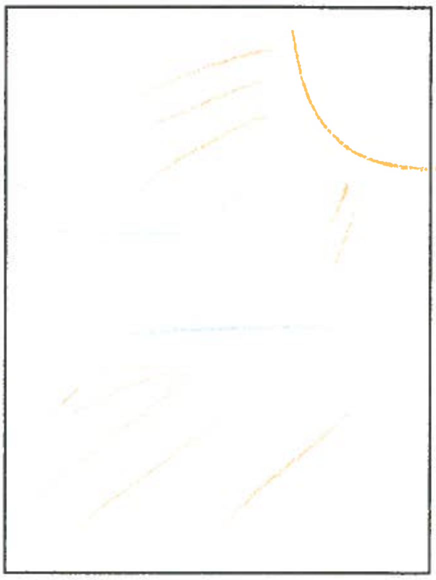


Snefnug!

2 15°

Jakke, Gråvejr

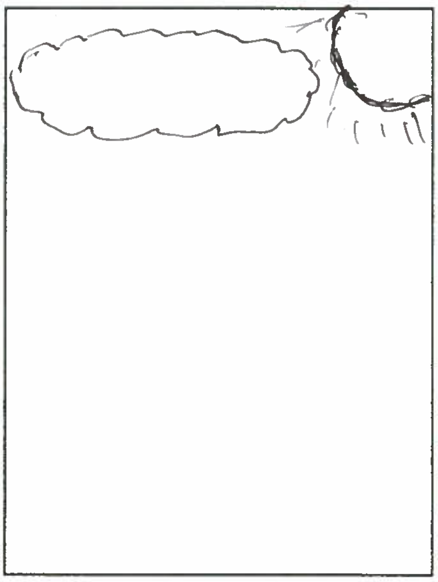
3 30°



Strand, sol

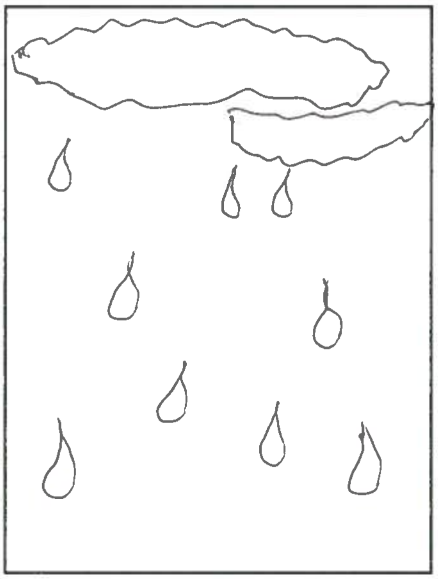
Nr. 3 Condition: down pour

1



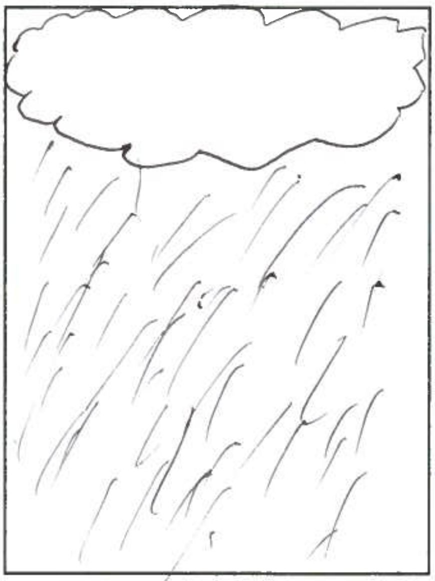
Sky, sol

2



regn

3



regn

Nr. 12 Condition: Temperature

1

2

3

termometer

Nr. Condition:

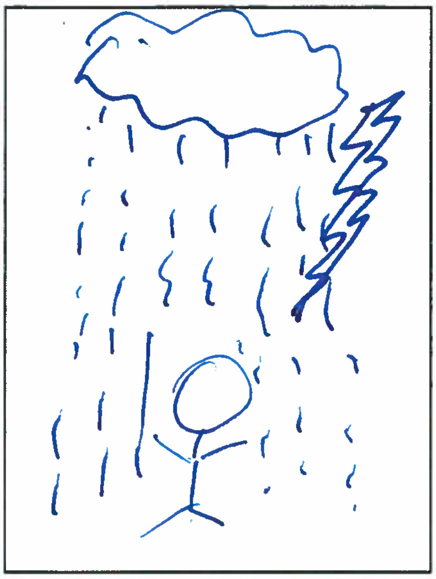
1

2

3

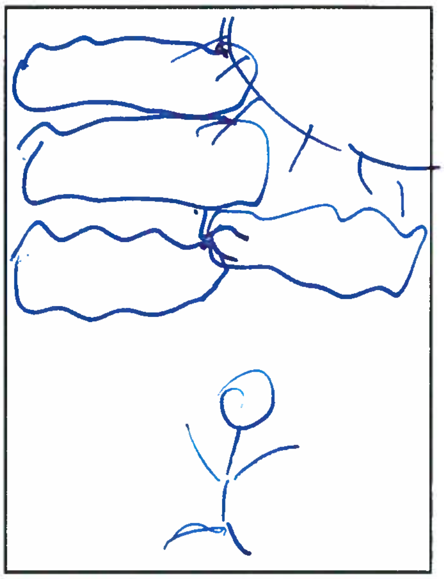
Nr. 25 Condition: Visibility

1



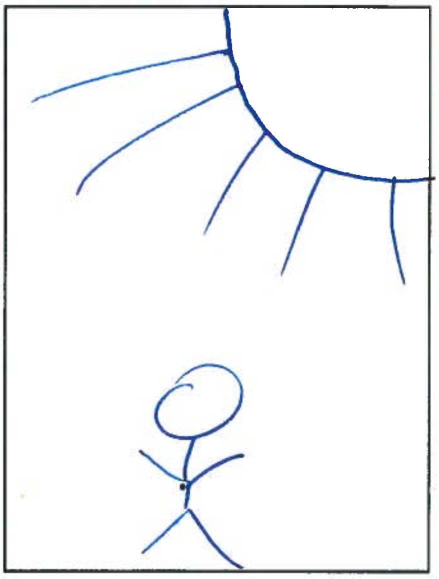
Strong storm

2



Cloudy weather

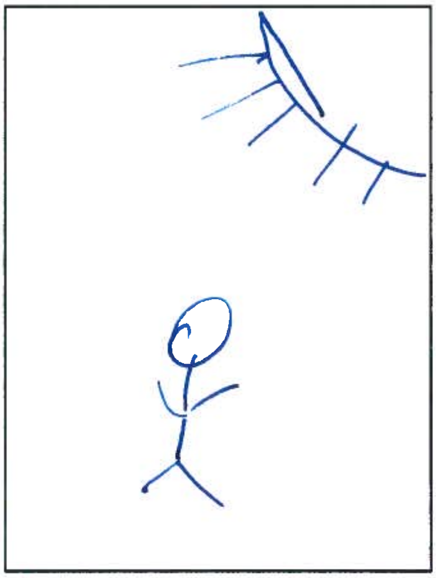
3



Sunny

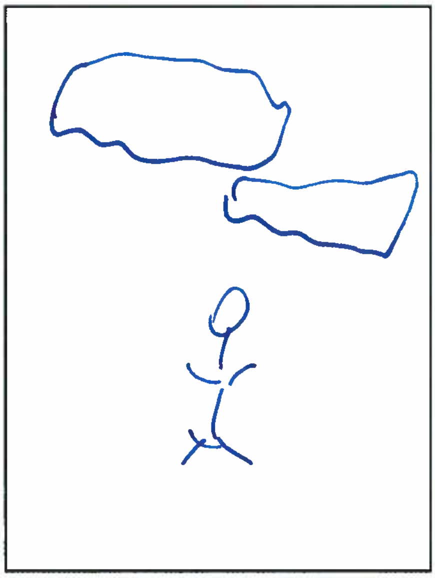
Nr. 26 Condition: cloud cover

1



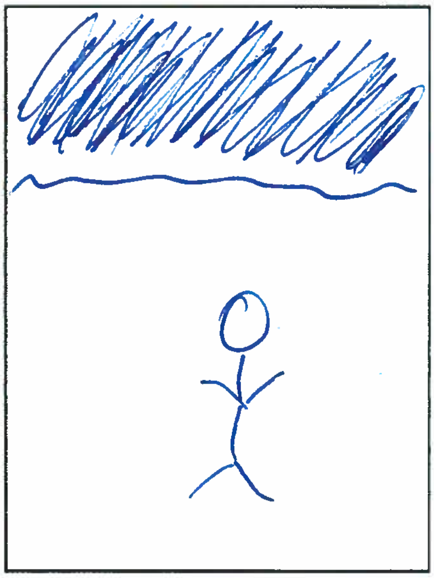
No cloud
Clear sky

2



Light cover sky

3



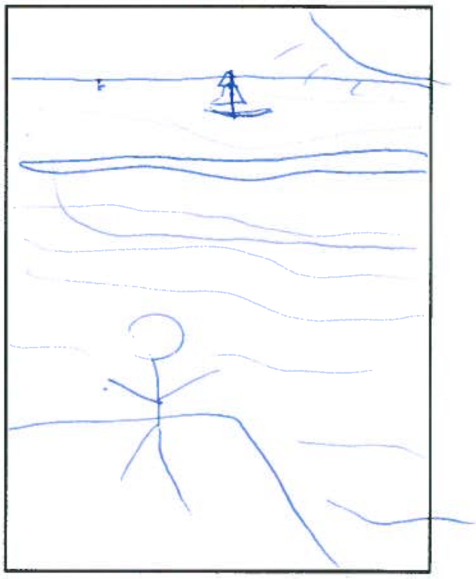
Complete cloudy

Nr. 19 Condition: Visibility.

1

2

3



Mand der kigger
af vinduet Skæl
Ud på en ~~kedelig~~ ...ig
dag.

Cykler og
cleter kedeligt
vejr

Hav. Horisont

Nr. 20 Condition: Cloud-cover

1

2

3

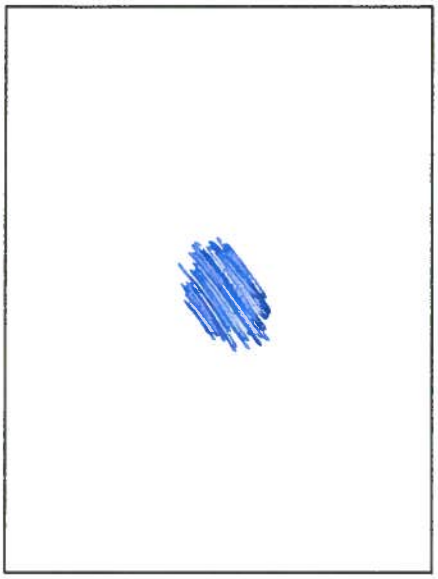
Ingen Skyer

lot overskyet
Ka se himmel
nogen Steder

Grå-himmel
Kan ikke se
himmel

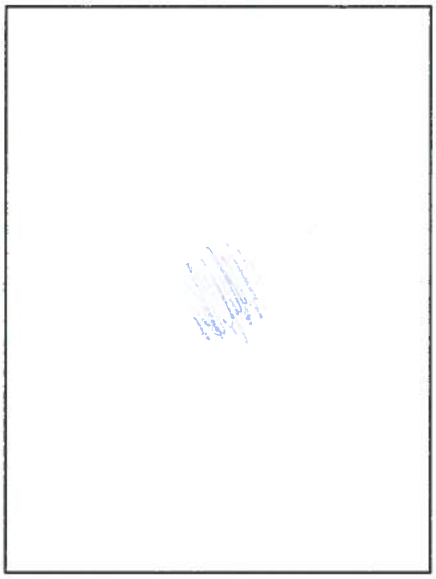
Nr. 9 Condition: Cloud Cove

1



Blue

2



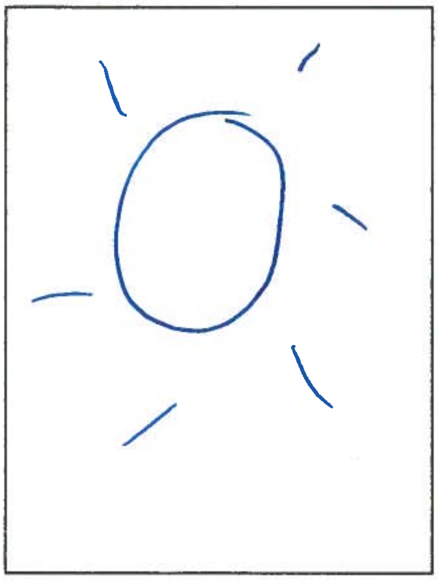
Light blue

3

white

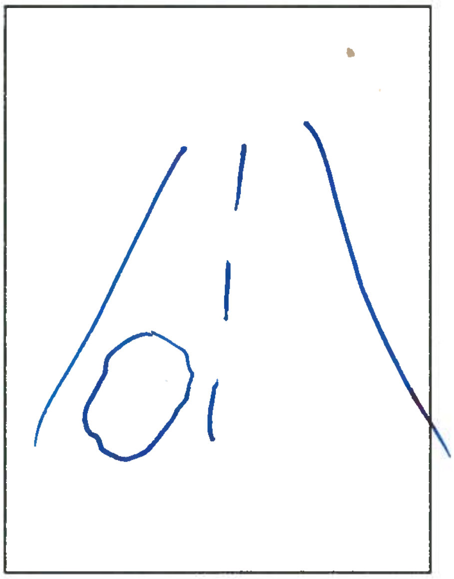
Nr. 10 Condition: Downpour

1



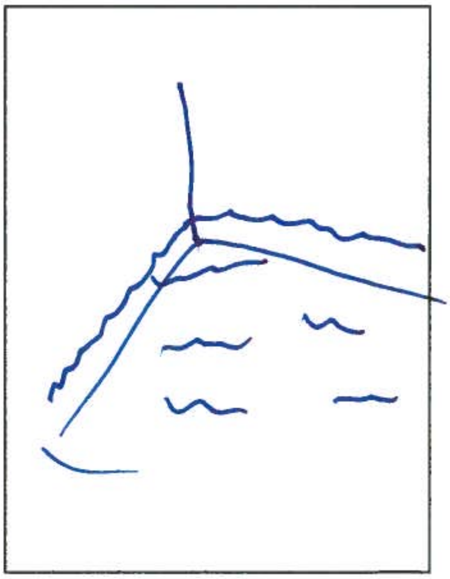
Sol

2



Vandpyt

3

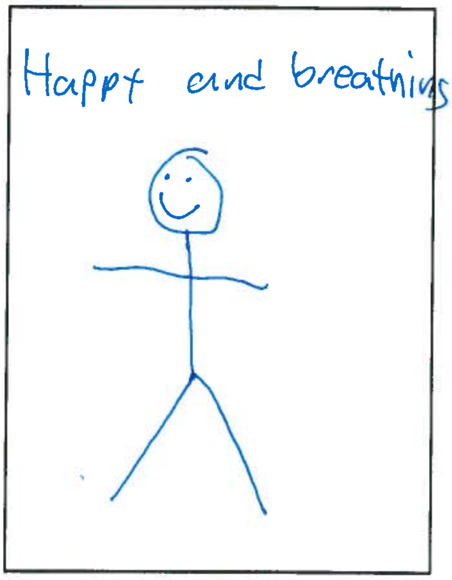


Oversvommelse

Nr. 17 Condition: Pollen

1

2



3

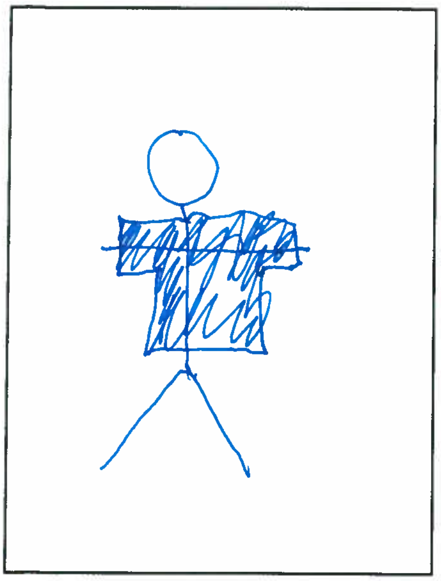
Glad og kan trække vejret

glad og kan trække vejret

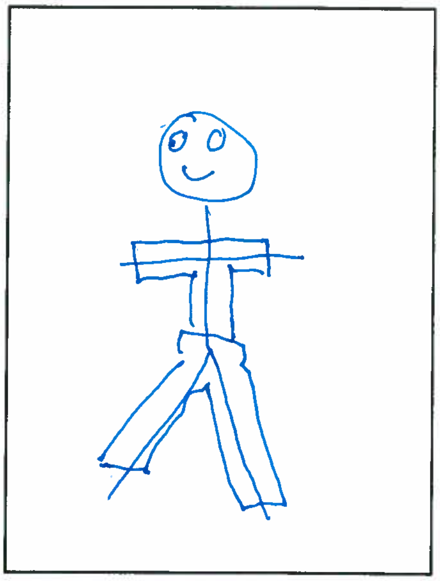
Øjnene løber og er tilstoppet

Nr. 18 Condition: Temperature

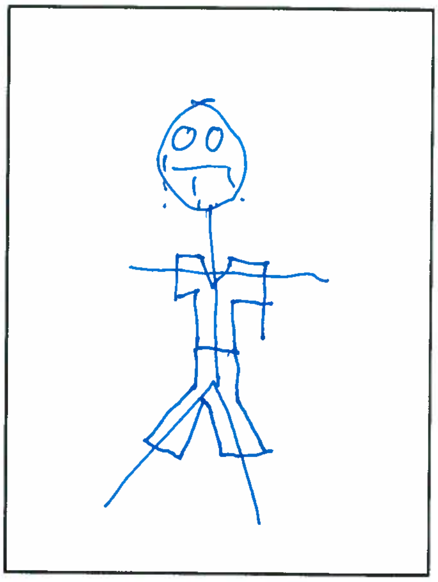
1



2



3



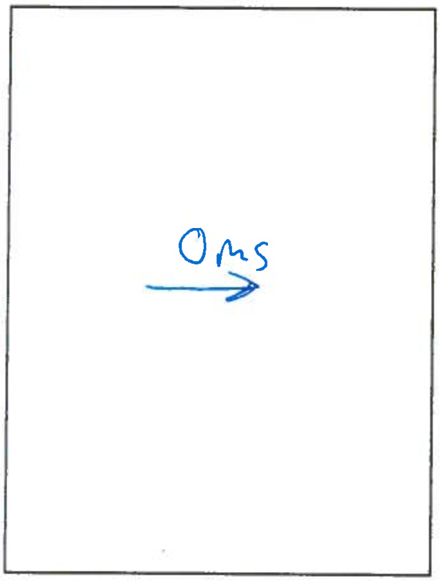
Stor og tyk Jakke

Jeans og normal Trøje, behagelig

Shorts og t shirt Sveder stadig

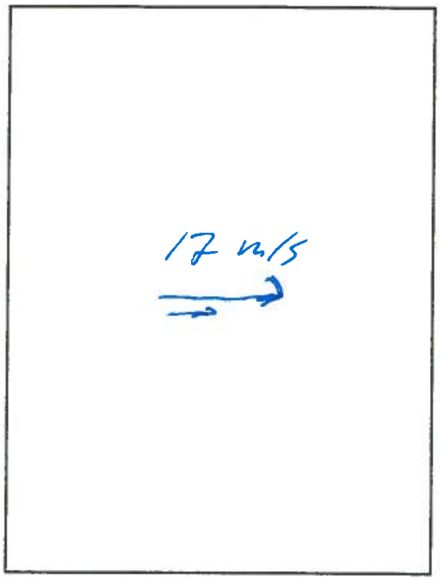
Nr. 15 Condition: wind speed

1



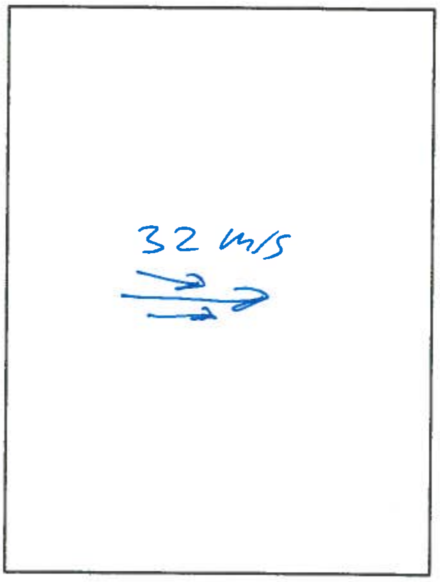
lav vindhastighed

2



middel vinde

3



høje vindhastigheder

Nr. 16 Condition: DownPour

1

lidt regn

2

middel regn

3

meget regn

A.2 Processed Results

Data type	Condition	#1	#2	#3	#4	#5	Possible solution	Alternative
Temperature	**Low**	Snowflake	Snowflake	Snowflake	Big coat	Thermometer showing 0 degrees.	Snowflake, snow	
	Medium	Wave form	Jacket, gray weather	Tree	Normal clothing	Thermometer showing 15 degrees		Average clothing
	High	Thermometer at high	Beach, sun	Sunny day, beach	Shorts, t-shirt, sweat	Thermometer bursting at 30	Sun and beach	Thermometer
Downpour	**low**	Sun	Cloud, light rain	Dry, sunny	Cloudy, indiferent person	Cloud, Sun	Sunny	Clouds, no rain
	Medium	Puddle	Cloud, medium rain	Scattered rain	Sun, man in raincoat	Rain	Clouds with rain	
	High	Flooding	Cloud, much rain	Powerful rain	Angry man, puddles	Heavy rain	Clouds with much rain	
Wind Speed	**Low**	Tent	Flag limp	Arrow 0m/s	Tree silent	Tree, no movement	Tree/flag without movement	
	Medium	X in middle of a scale	Waving flag	two arrows 17 m/s	Tree banking to the left	Flag, waving	Tree/flag with some movement	
	High	Man in storm	wave symbol	Three arrows 32m/s	Tree overturns	Tree and flag bending	Tree/man against much wind	
Pollen	**Low**	Sun	Man, happy, breathing	Man, skiing	Happy man	Man, happy	Man, happy/smiling	
	Medium	Foggy sun	Man, happy, breathing	Tree	Man, sneezing	Man, sneezing	Man, sneezing	
	High	Covered sun	Face, red eyes, runny nose	Man, runny nose	Man, tears, runny nose	Man, sneezing, itching	Man w. runny nose, red eyes or itching	
Visibility	**Low**	Man, looking out on "boring" day.	Strong storm	Man in mist	Window, gray	Cloudy	Window, gray outsode	
	Medium	Biking, boring weather	Cloudy	Three people in mist, two can see each other	Window, light gray with clouds	Less cloudy	gray colors	Cloudy
	High	Sea, Clear horizon	Sunny	Waving to man in distance	Window, clear day	Clear weather	Clear day, sun	
Cloud cover	**Low**	Sunny day, no clouds	Clear sky	Color blue	No clouds, clear	Clear sky	Clear day, sun	
	Medium	One cloud, a bit of sun	Light clouds	Color ligt blue	Light clouds	Light clouds	few clouds	
	High	Dark clouds	Overcast	color white	Gray sky	overcast	overcast	
UV-index	**Low**	Eyes	Cloudy	Cloudy	Small sun	Cloudy day	cloudy day	
	Medium	Sun screen	Cloud, Sun	Cloudy, Sun	Average sized sun	Warm but cloudy	clouds, sun	
	High	Sun glasses	Sun with sun glasses, fried egg	Full sun, heat waves	Big sun	Sun, no clouds	sun, no clouds	

B Auditory Pre-test

B.1 Pre-test 1 results

Auditory Pre Test 1: Results

Temperature

Description: Current air temperature 2 meters above terrain.

Questions: How would you define a sound for a high Temperature?
How would you define a sound for a low Temperature?

1	**High:** : water boiling	**Low:** Snow storm
2	**High:** sound of a tea pot whistle	**Low:** Walking through snow
3	**High:** burner	**Low:** Ice breaking
4	**High:** insect swarm	**Low:** Person shaking and cold
5	**High:** High pitch tone	**Low:** Deep tone
6	**High:** Pass	**Low:** Pass
7	**High:** Pass	**Low:** Pass
8	**High:** person who has it hot and breathing heavily	**Low:** Teeth grinding
9	**High:** boiling sounds	**Low:** Something cold
10	**High:** High pitch Tone	**Low:** Deep tone
11	**High:** air vibrating	**Low:** Ice breaking
12	**High:** a light tone / something boiling	**Low:** Ice breaking

Wind Speed

Description: Average wind speed over 10 minutes, 10 meters above terrain.

Questions: How would you define a sound for high Wind Speed?
How would you define a sound for low Wind Speed?

1	**High:** High wind gust	**Low:** Low wind gust
2	**High:** High wind gust	**Low:** Low wind gust
3	**High:** High wind gust	**Low:** Low wind gust
4	**High:** Trees rustling	**Low:** Trees rustling less
5	**High:** Tornado – Cow in a tornado	**Low:** Pass
6	**High:** High wind gust	**Low:** Trees rustling
7	**High:** Friction noise (higher wind = more noise)	**Low:** friction noise (low wind = less noise)
8	**High:** person who has it hot and breathing heavily	**Low:** Less wind
9	**High:** Wind sounds	**Low:** Less wind
10	**High:** Wind sounds	**Low:** Less wind
11	**High:** Wind sounds	**Low:** Less wind
12	**High:** Wind sounds	**Low:** Less wind

Precipitation

Description: Rain/Sleet/Snow/Hail over the past ten minutes measured in mm.

Question: *How would you define a sound for Precipitation - Rain?*
How would you define a sound for Precipitation - Sleet?
How would you define a sound for Precipitation - Snow?
How would you define a sound for Precipitation - Hail?

Results:

1 - Rain: The sound of rain on a road
Snow: snow
Hail: hail

2 - Rain: rain
Snow: snow
Hail: stones on a roof

3 - Rain: sound of rain
Snow: cold weather
Hail: hail

4 - Rain: rain
Snow: footstep in the snow
Hail: hail on a rooftop

5 - Rain: sound of rain
Snow: snow
Hail: stones or hail hitting the roof

6 - Rain: rain drops
Snow: snow
Hail: hail

7 - Rain: rain on window
Snow: footstep in the snow
Hail: cold rain / hail

8 - Rain: sound of rain
Snow: footstep in the snow
Hail: something hard hitting the ground

9 - Rain: sound of rain
Snow: sound of snow
Hail: sound of hail

10 - Rain: drips
Snow: walking in snow
Hail: Golf balls

11 - Rain: rain
Snow: crunching
Hail: small balls falling to the ground

12 - Rain: drip
Snow: wind gust
Hail: Pas

Pollen Forecast

Description: The potency of the pollen.

Question : How would you define a sound for a low Pollen Forecast?
How would you define a sound for a high Pollen Forecast?

1	**High:** Pass	**Low:** Pass
2	**High:** Pass	**Low:** Pass
3	**High:** Pass	**Low:** Pass
4	**High:** Sneeze	**Low:** Pass
5	**High:** Sneeze	**Low:** Pass
6	**High:** a plant blowing up	**Low:** Pass
7	**High:** sneeze, you gonna die now (starwars theme)	**Low:** Pass
8	**High:** Sneeze	**Low:** sound of fresh air
9	**High:** sneezing and wet noose	**Low:** nothing
10	**High:** sound of twigs rustling	**Low:** Grass blowing
11	**High:** Sneeze	**Low:** Pass
12	**High:** screaming at home	**Low:** Pass

Visibility

Description: How far you can see with a clear line of sight.

Question How would you define a sound for visibility?

1	Classical sfx sounds of fog
2	Cars crashing
3	Pass
4	Classical sfx sounds of fog
5	Fog machine
6	Pass
7	fog horn
8	muffled
9	zoom zoom sound
10	Pass
11	Slow wind sound
12	Muted tone / sock on a mic

B.2 Pre-test 2 results

Appendix (XX). – Pre test 2

Auditory Pre Test 2: Results

List of Sounds:

1. Hail – Downfall Hail
2. Rain – Downfall Rain
3. Snow – Downfall Snow
4. Birds – Downfall Nothing
5. Horn - Fog
6. Sneeze - Pollen
7. Kettle – High Temperature
8. Teeth – Low Temperature
9. Small breeze – Medium Temperature
10. Wind – Wind Speed

Test 1

1.	Hail	Correct
2.	Rain	Correct
3.	Bag	Incorrect
4.	Birds	Correct
5.	Horn	Correct
6.	Sneeze, Sickness	Correct()
7.	Kettle	Correct
8.	Clock	Incorrect
9.	Bad weather	Correct()
10.	Wind	Correct

Test 2

1.	Broken Sticks	Incorrect
2.	Rain	Correct
3.	Walking on gravel	Incorrect
4.	Bird	Correct
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	Playing with a ball	Incorrect
9.	Bad weather	Correct()
10.	Wind	Correct

Test 3

1.	Hail	Correct
2.	Rain/Thunder	Correct()
3.	–	Incorrect
4.	Birds/Nature	Correct()
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	Writing machine	Incorrect
9.	Weather	Correct()
10.	Wind/Storm	Correct()

Test 4

1.	Car or Hail	correct()
2.	Rain	Correct
3.	Walking in Snow	Correct()
4.	Bird	Correct
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Screaming Kid	Incorrect
8.	Taximeter	Incorrect
9.	Weather	Correct()
10.	Wind	Correct

Test 5

1.	Hail	Correct
2.	Rain	Correct
3.	Walking on gravel	Incorrect
4.	Bird	Correct
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	Old Watch	Incorrect
9.	Bad weather	Correct()
10.	Wind	Correct

Test 6

1.	Hail	Correct
2.	Rain	Correct
3.	Paper	Incorrect
4.	Summer evening	Incorrect
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	Fork on a plate	Incorrect
9.	Bad weather	Correct()
10.	Wind	Correct

Test 7

1.	Hail	Correct
2.	Rain	Correct
3.	Paper	Incorrect
4.	Summer evening	Incorrect
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	Clock	Incorrect
9.	Bad weather	Correct()
10.	Though Wind	Correct()

Test 8

1.	Hail	Correct
2.	Rain	Correct
3.	-	Incorrect
4.	Forrest	Incorrect
5.	Ferry	Correct()
6.	Sneeze	Correct
7.	Kettle	Correct
8.	-	Incorrect
9.	-	Incorrect
10.	Wind	Correct

Test 9

1.	-	Incorrect
2.	Rain	Correct
3.	-	Incorrect
4.	Sunshine	Incorrect
5.	-	Incorrect
6.	Sneeze	Correct
7.	Kettle	Correct
8.	-	Incorrect
9.	-	Incorrect
10.	Wind	Correct

Test 10

1.	Throwing Stones	Incorrect
2.	Rain	Correct
3.	Gravel	Incorrect
4.	Rain Forrest	Correst()
5.	Horn	Correct
6.	Sick	Incorrect
7.	Boiling	Correst()
8.	-	Incorrect
9.	-	Incorrect
10.	Storm/Tornado	Correst()

B.3 Pre-test 3 results

Appendix (XX): Auditory Pre Test 3

Auditory Pre Test 3: Results

Sound 1 (DownFallHail):

1. Hail
2. Hail
3. Hail
4. Heavy rain on a car
5. A lot of Hail
6. Hail
7. Hail
8. Hail
9. Hail
10. Hail

Sound 2 (DownFallRain):

1. Rain
2. Rainy
3. Rain + Thunder
4. Storm – Thunder – Lightning
5. Heavy rain + thunder
6. Rain + Thunder
7. Rain + Thunder
8. Stormy
9. Rain
10. Rain + thunder

Sound 3 (DownFallSnow):

1. Frozen Snow
2. Snow
3. Walking on snow
4. Snow/ice gravel
5. Snow perhaps
6. Snow
7. No idea maybe snow?
8. Snow
9. Frozen snow
10. Thaughed snow

Sound 4 (DownFallSun):

1. Clear weather
2. Sunny spring
3. Sunny + Clear weather
4. Sunny + light wind
5. Sunny
6. Sunny
7. Summer Sun
8. Sunny
9. Sunny
10. summer

Sound 5 (Fog):

1. Foggy
2. Pas
3. Pas
4. Grey, damp, sea wind
5. Fog
6. Pas
7. Maybe fog?
8. Fog
9. Fog
10. fog

Sound 6 (Pollen):

1. Pollen
2. Pollen
3. Cold
4. Cold – wet
5. Pollen
6. Pollen
7. Cold and windy
8. Cold
9. Pollen
10. Pollen

Sound 7 (TempHigh):

1. HOT!!!!
2. High temperature
3. Boiling water
4. Cold, high wind (kettle boiling)
5. Very hot
6. Very hot
7. 100 degrees warm
8. Very hot
9. Hot
10. burning

Sound 8 (TempLow):

1. Weird
2. Pas
3. Pas
4. Cold, clattering teeths
5. Very cold
6. Very cold
7. Frozen -20 degrees
8. Very Cold
9. Cold
10. pass

Sound 9 (TempMed):

1. Chilly/cold
2. Hot
3. Pas
4. Light wind - warm
5. Mild wind – cozy degree
6. Pas
7. 10-15 degrees mild weather
8. Mild
9. Normal weather
10. Average

Sound 10 (Windspeed):

1. Storm
2. A lot of rain and wet
3. Windy and cold
4. High Wind, Snow, Blizzard
5. Windy
6. Very windy
7. Storm
8. A lot of wind
9. Storm
10. storm

C Evaluation Test Results

C.1 Test Result Data

Low: Visual Elements

Temperature	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Rain	1	1	1	1	1	1	1	2	1	2	1	1	1	2	2	2	1	2	1	2	
Wind Speed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Visibility	1	1	1	2	2	2	2	2	2	2	1	1	1	1	2	2	2	2	1	2	Inverse
pollen	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	2	1	1	1	3	

Medium: Visual Elements

Temperature	2	2	1	2	1	2	1	3	1	1	1	1	1	1	2	1	1	1	1	1	
Rain	1	1	1	2	2	2	2	2	2	2	2	2	2	3	2	1	1	2	1	1	
Wind Speed	2	3	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	
Visibility																					Inverse
pollen																					

High: Visual Elements

Temperature	3	3	2	3	3	2	3	3	3	3	3	2	2	3	3	3	3	2	3	3	
Rain	3	3	2	2	2	3	3	2	2	2	2	2	3	3	3	2	3	3	2	3	
Wind Speed	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	
Visibility	2	2	2	2	3	2	3	3	2	2	2	3	3	2	3	3	2	3	3	3	Inverse
pollen	3	3	3	3	3	3	3	3	2	3	2	2	3	3	3	3	3	3	3	3	

Low: Sound and Visual Elements

Temperature	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Rain	3	3	3	1	2	2	1	3	1	3	2	1	1	3	1	2	1	1	3	2	
Wind Speed	2	2	2	2	1	1	2	2	1	1	2	1	2	1	1	1	2	1	1	2	
Visibility	1	1	2	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	Inverse
pollen	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Medium: Sound and Visual Elements

Temperature	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Rain	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Wind Speed	3	2	2	3	2	2	3	2	3	2	2	2	2	3	2	2	2	3	2	2	
Visibility																					Inverse
pollen																					

High: Sound and Visual Elements

Temperature	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Rain	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Wind Speed	3	2	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	
Visibility	3	3	2	3	2	3	2	2	3	2	3	3	3	2	3	2	3	2	3	2	Inverse
pollen	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	

Low: Sound Elements

Temperature 1	1	1	1	2	1	1	1	1	1	2	1	2	1	2	1	2	1	1	1	1
Rain 1	2	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2
Wind Speed 1	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	1	2	2	2	1
Visibilty 1	1	2	1	1	3	1	1	1	1	2	3	1	1	1	1	1	1	1	2	1
pollen 1																				

Medium: Sound Elements

Temperature 2	2	1	1	2	1	1	2	2	2	1	2	2	2	2	2	2	1	2	1	1
Rain 2	3	3	3	3	3	2	2	3	3	3	3	2	2	3	3	3	3	3	3	2
Wind Speed 2	3	2	2	3	2	3	2	2	3	2	3	2	2	2	3	3	3	2	2	3
Visibilty 1																				
pollen 1																				

High: Sound Elements

Temperature 3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3
Rain 3	3	2	3	1	2	2	3	2	2	2	3	3	3	2	3	3	2	2	3	3
Wind Speed 3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Visibilty 1																				
pollen 1	3	3	3	2	2	3	3	2	2	2	1	3	3	3	2	3	3	2	3	2

C.2 Test Result Graphs

Low Values

A

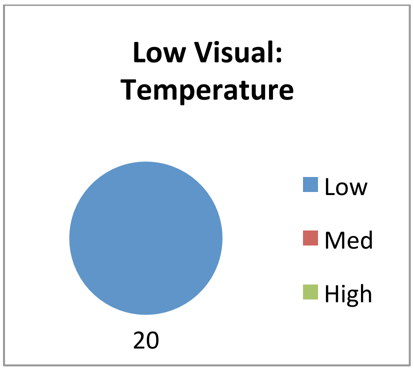


Figure 1

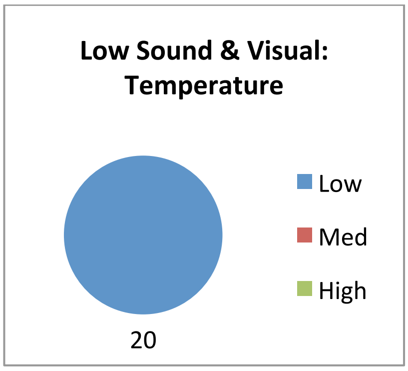


Figure 2

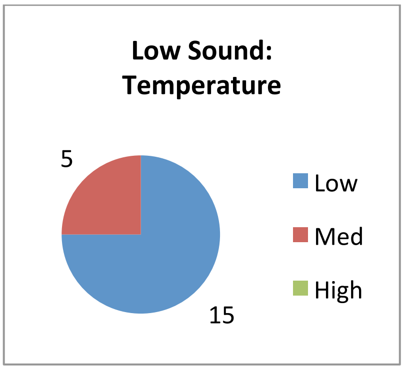


Figure 3

B

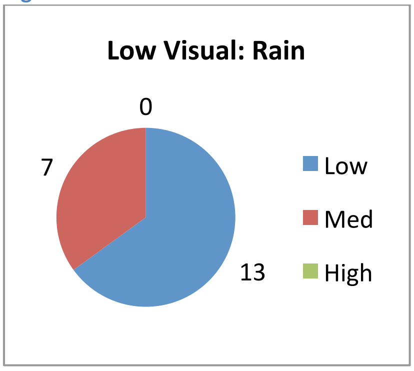


Figure 4

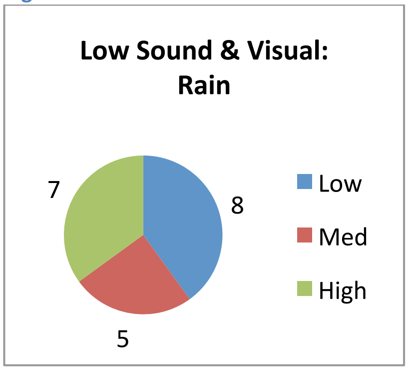


Figure 5

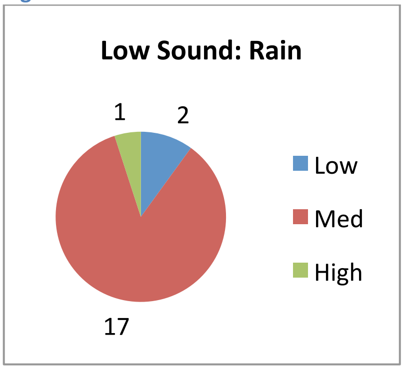


Figure 6

C

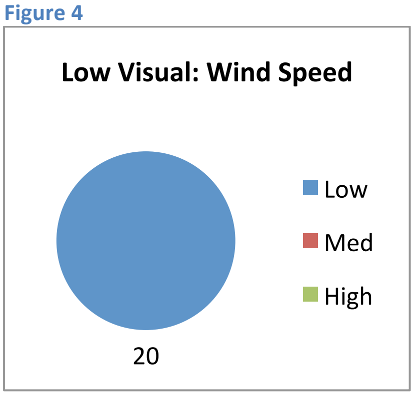


Figure 7

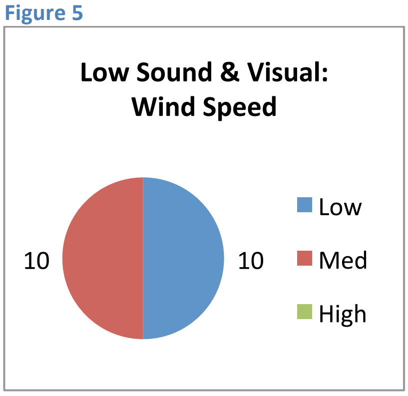


Figure 8

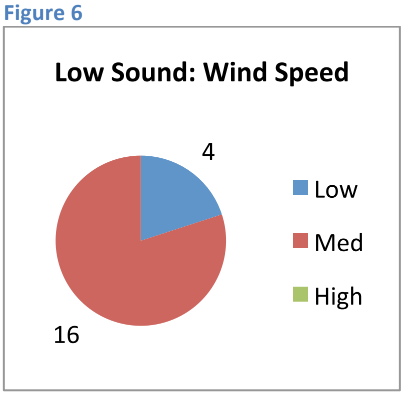


Figure 9

Appendix Test result graphs

D

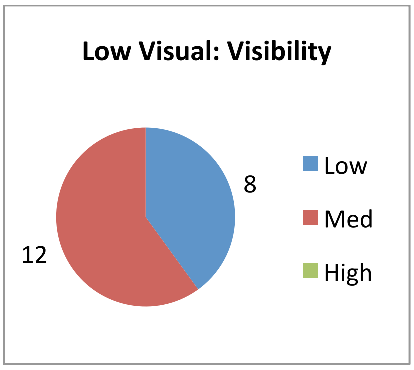


Figure 10

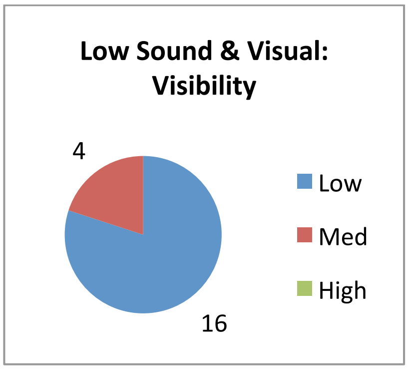


Figure 11

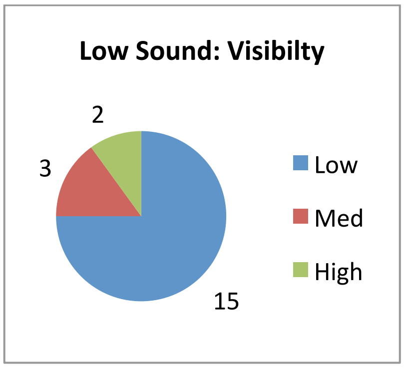


Figure 12

E

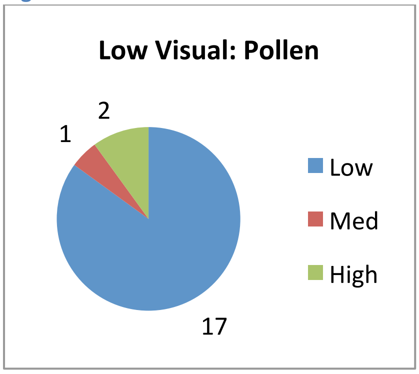


Figure 13

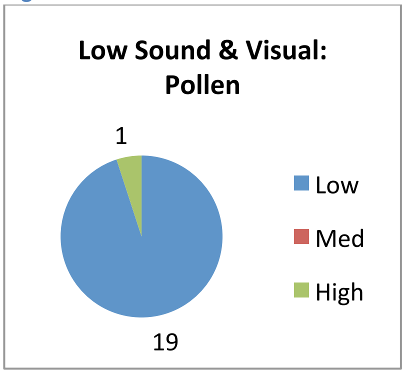


Figure 14

No Sound for low pollen.

Medium Values

F

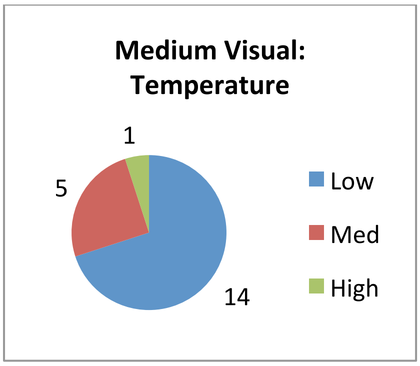


Figure 15

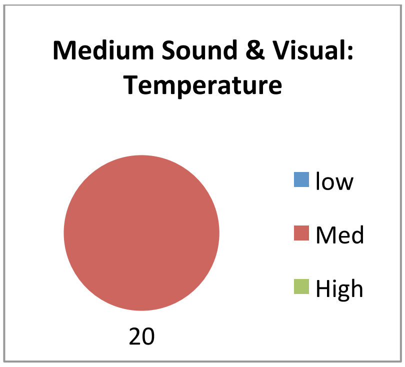


Figure 16

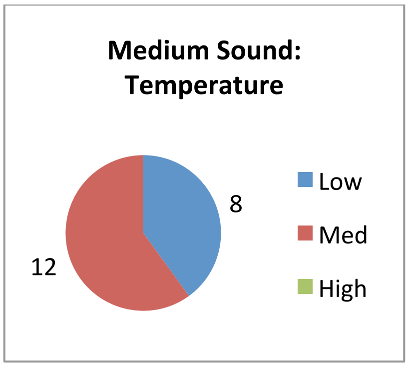


Figure 17

G

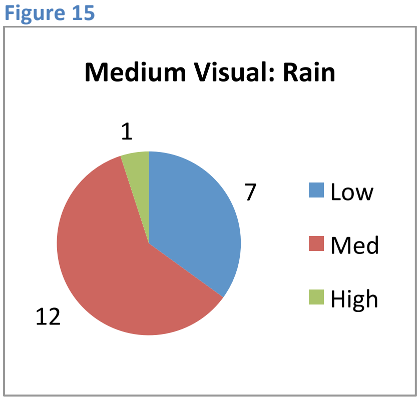


Figure 18

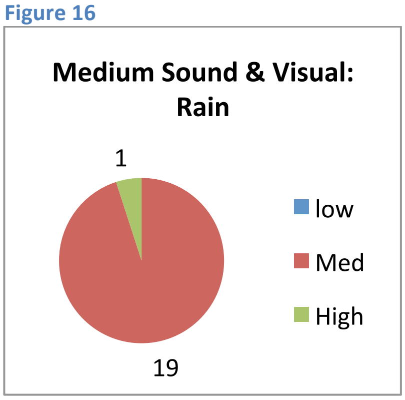


Figure 19

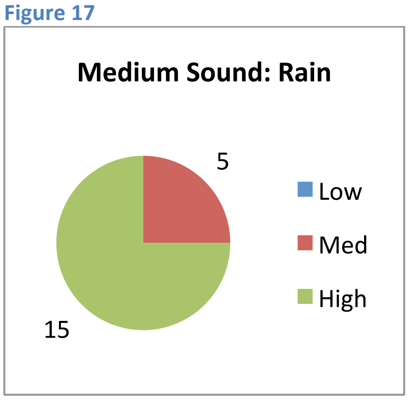


Figure 20

H

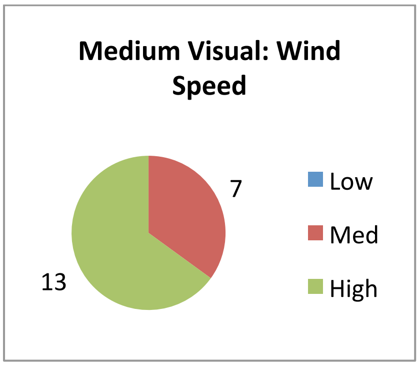


Figure 21

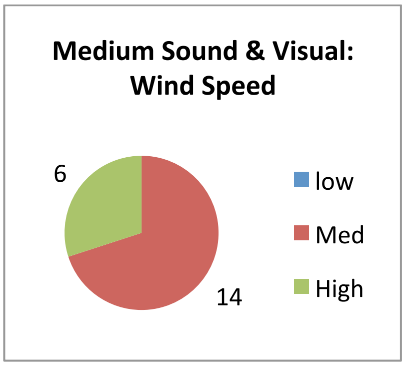


Figure 22

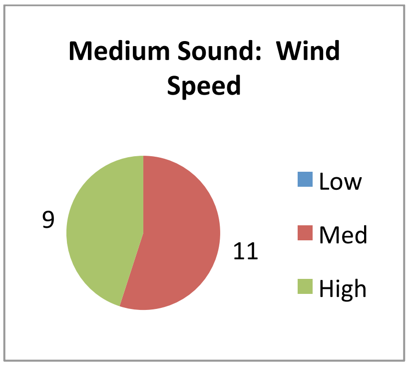


Figure 23

HIGH VALUES

I

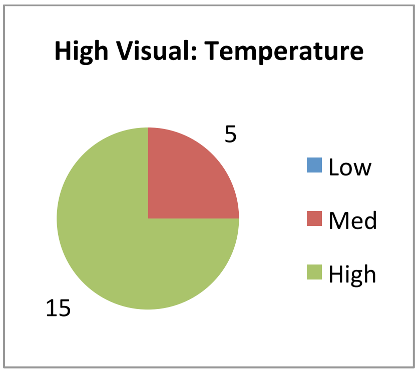


Figure 24

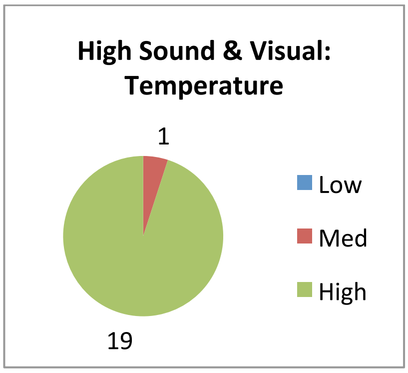


Figure 25

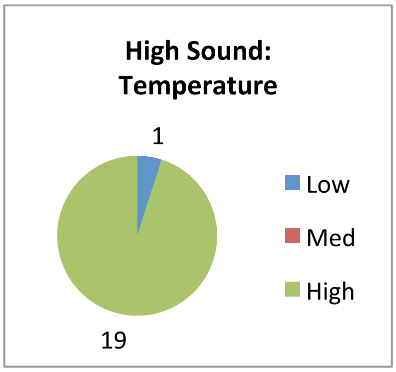


Figure 26

J

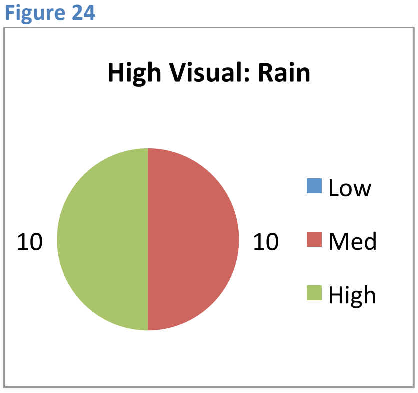


Figure 27

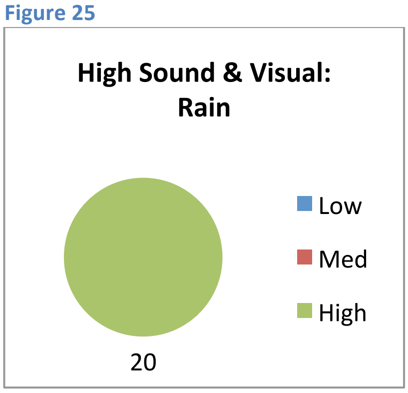


Figure 28

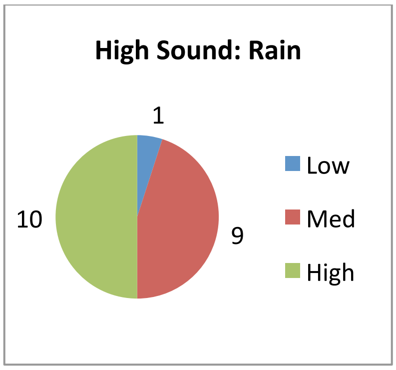


Figure 29

K

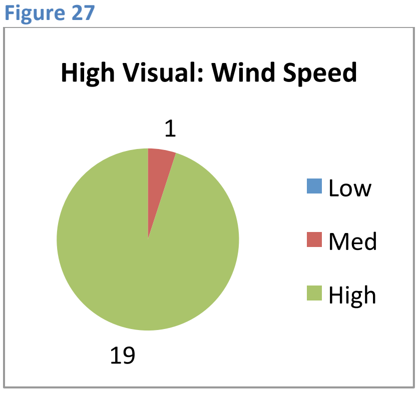


Figure 30

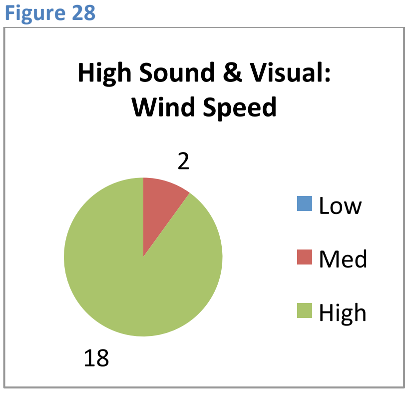


Figure 31

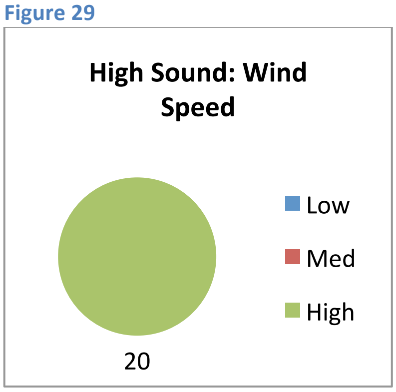


Figure 32

Appendix

Test result graphs

L

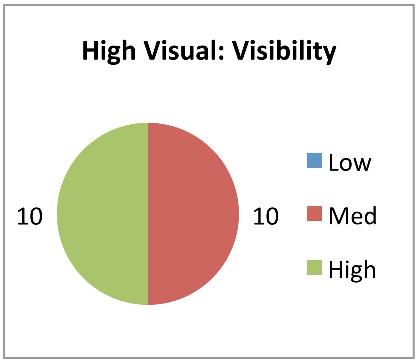


Figure 33

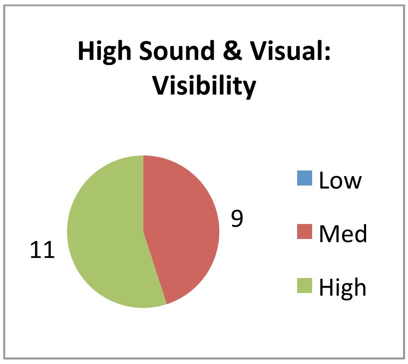


Figure 34

No sound for high visibility

M

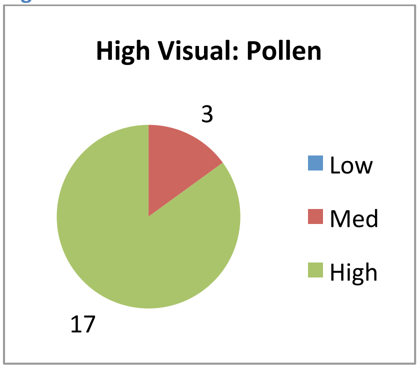


Figure 35

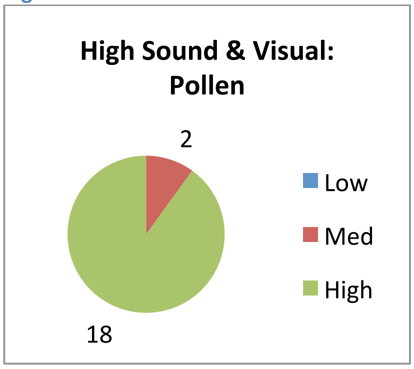


Figure 36

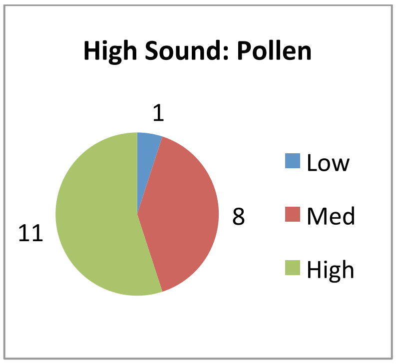


Figure 37