Wearable Breathing Trainer Project

Textile integration of the breathing sensors and haptic feedback panel

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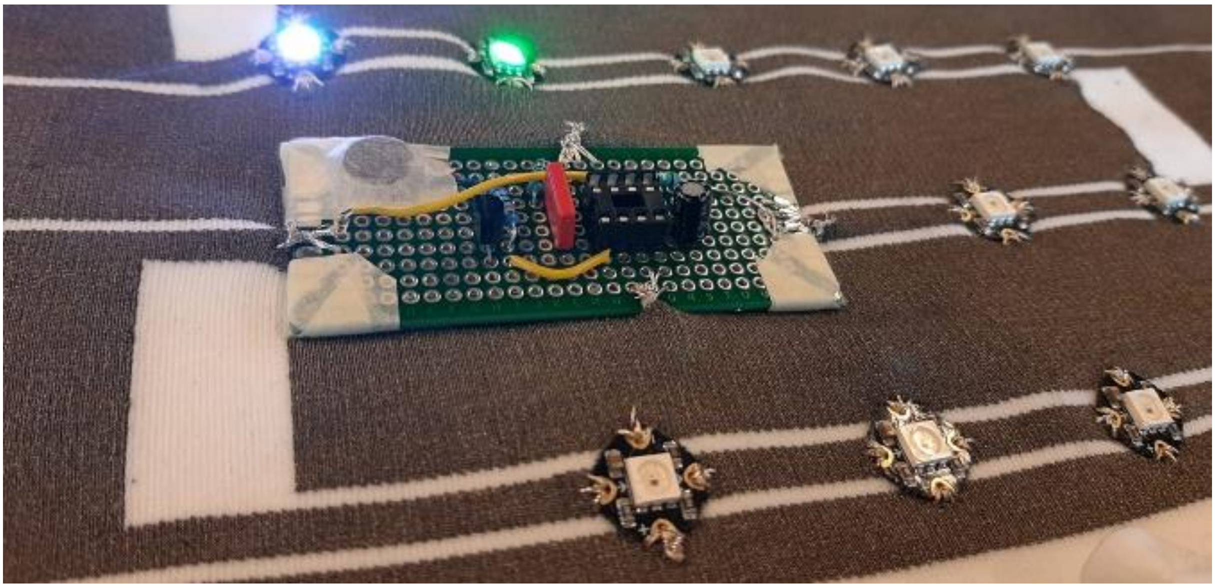

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Table 1. List of Abbreviations

Abbreviation	Explanation
WBT	Wearable Breathing trainer
S&FT	Sustainable & Functional Textiles
PCB	Printed circuit board
IC	Integrated circuit

Preface

This report was carried out for the research group Sustainable & Functional Textiles. The report will be the final thesis of the author for the Bachelor study; Fashion and textile technologies.

I would like to thank all the people working at the research group for sharing their knowledge, especially Hellen van Rees, who was project leader of the WBT project and gave me constant feedback throughout the process of writing this report. As well as Sven Kamphuis who took the time to explain everything I needed to know about the circular knitting machine in the knitting lab.

I had the luck to have access to a lot of knowledge trough project partners of the WBT project. I would like to thank the experts; Ben Bulsink from Breathpal and Miriam Geelhoed from Modint for sharing their knowledge with me, and taking their time to explain me their expertise.

Furthermore at Saxion; Harry Sanderink for helping me with the grid, Musaab al Muqbali for helping me with the resistance testing, Steven Reinink for helping me with the knitting machine, Gemma Ciabattoni for helping me with overall electronic side and Evelyn Lebis together with my study group with fellow students to help me with the overall structure of my report.

Enschede,

16-06-2022,

Sanne Schuttert.

Synopsis

In section 1 the problem definition is 5 % of all kids in the Netherlands suffer from dysfunctional breathing (Ludden, Mader, van Rees, & Siering, 2019). The research group S&FT has a project: the WBT. This project focuses on personalised care for children ages 6-12 with breathing disorders by means of a motivating textile wearable. The general problem with the existing prototype is that the technology isn't well integrated in the textile product.

What needs to be achieved with this research is a comfortable, robust, safe and practical WBT prototype. To allow for sufficient focus and depth needed for the project, this research is aimed specifically at integrating the breathing sensor and the LED-/vibration panel into a textile.

Following this, is section 2 in which necessary information is gathered to start the design process. This happens by means of literature, expert meetings and brainstorm sessions. This gives a clear conclusion on what parameters the product needs to have to fulfil the criteria set in section 1.

The breathing sensors of the WBT should be integrated into the main layer of the vest. This should be done by knitting the body of the vest with 2 conductive tracks; one at the abdominal and one at the breast. The knitted track should have a resistance below at least 13 Ohm, but the lower the better. The size of these tracks should be around 60 CM long and 2 CM wide.

The feedback panel of the WBT should be located behind the main layer of the vest in the abdominal area. The optimal layout for this panel should be in series. It would also be preferable if the textile panel would be somewhat thick and stable to protect the electronics and prevent them from moving too much. The connection points of the electronics should be integrated in the textile by means of knitting with conductive yarn.

Furthermore in section 3 the design refinement is shown. Based on the conclusion in section 2 all the different samples and tests to abide by these set parameters are shown. Different samples were produced until good final samples were attained. These 2 samples and the way they are produced are the conclusion of the design refinement; breathing sensors should be knitted with a width of 1181 needles and 200 rows with conductive yarn and the PurleMiss3x3.Pat structure. The feedback panel works with the LEDs and vibration motors in series on a knitted structure.

In section 4 the 2 sample conclusions of section 3 are combined to make the final prototype of this research. A technical drawing and the final material choice are explained. This prototype satisfies almost all of the design criteria, however some tests were not able to be carried out in this stage of the WBT project.

The most important findings were implemented in smart textile lessons for the future textile experts.

Section 1 Introduction to the research

1.1 Problem definition

5% of all kids in the Netherlands suffer from dysfunctional breathing (Ludden, Mader, van Rees, & Siering, 2019). A lot of these kids have trouble with their breathing exercises and could really use a WBT. The research group S&FT has a project: the WBT. This project focuses on personalised care for children ages 6-12 with breathing disorders by means of a motivating textile wearable (Ludden, Mader, van Rees, & Siering, 2019).

The idea is that the vest (Table 2) can be worn during breathing exercises. With 2 breathing sensors the breathing of the child will be measured. The sensors are located around the abdomen and the chest in the main layer of the vest. To improve the measured breathing haptic feedback will be given through vibration motors during the breathing exercises. These are located at the layer below the main body of the vest. At the end of the breathing exercise an amount of LED lights will go on. These are located at the same layers as the vibration motors and shine through the main body of the vest. These LEDs are a reward system for the child that may be linked to an app.

Table 2. Pictures existing prototype

Breathing elastics location in existing prototype	Panel with the electronics of the existing prototype
	

Within the WBT project a prototype was developed with the main functions of the wearable. Namely measuring chest and abdominal breathing and delivering haptic feedback based on the breathing. Although it works, it is now only to demonstrate the principle, and the technology integration is rudimentary.

The general problem with the existing prototype is that the technology isn't well integrated in the textile product. The functional components of the WBT need to be integrated more robust, comfortable and reproducible. But with replacing non robust and not well integrated components with integrated conductive textile, aspects like low resistance and stable connections become very important.

The prototype has two rows of sensor elastic, so called Rip-Sensors, that detect and measure breathing (Table 2). These elastics need 2 'tunnels' in the shirt and all together create a lot of unnecessary bulk to the product. This way of intergrading the breathing sensors are not comfortable and robust enough for practical use on children.

Located on the abdomen part of the prototype is a separate textile panel on the inside (Table 2). This panel contains LED lights and vibration motors that deliver feedback from the breathing sensors to the child using it. The conductive yarns connecting the lights are now stitched on by hand. The LED lights are glued or soldered by hand. This way of producing is not appropriate for industrial scale, different methods should be researched and tested. The wires connecting the motors and the LED lights to the battery are too long and not secured in a robust way. Also the whole battery and PCB part is too bulky and fragile. The closure of the prototype is now located at the side seam of the shirt. This will be moved to the middle front of the shirt for wearability reasons. This means that the panel should be split in two or another solution needs to be found for the panel.

1.2 Design brief

1.2.1 Design brief

A comfortable, robust, safe and practical WBT prototype needs to be achieved with this research. In order to allow for sufficient focus and depth needed for the project, this research is aimed specifically at integrating the breathing sensor and the haptic feedback (LED-/vibration) panel. The PCB, battery, buttons and interconnections between these are out of the scope of this research project.

The prototype should be produced with industrial techniques appropriate for bigger scale production. If this thesis research is successful, the WBT project partners will have insight into the appropriate technology to use in the production of this prototype as well as prototypes and samples of these solutions. This will enable the project to proceed to its next steps with a fundamental basis on functional & reliable textile integration.

1.2.2 Design criteria

The WBT project covers a lot of aspects such as: making children understand the importance of the breathing exercises and to motivate the practicing of these exercises in a fun and playful way. Aspects like this are outside of the scope of this research which focuses on the technical further development of the existing WBT prototype into a more comfortable, robust, safe to use and practical garment, by means of more industrial scale techniques like knitting and embroidering. Therefore, only Table 3. Design criteria within the scope of the research will be mentioned.

The biggest functions of the garment is measuring chest/abdominal breathing and giving haptic feedback. The garment needs to be comfortable to wear and this is best achieved if the sensors and feedback panel are integrated into the textile. This should also make the part that touches the skin soft and less bulky. Since the product is for children between the age of 6 to 12, it should be child safe and possible for them to put in on themselves. While doing this the garment should be robust enough for everyday use. The techniques achieving this should be appropriate for industrial scale production to ensure that the product will actually hit the market.

Table 3. Design criteria

1.	The prototype should be a smart textile wearable that is safe for children.
2.	Children should be able to take on and off the garment by themselves.
3.	The inside and outside of the garment should feel soft on the skin like textile. This should be achieved by integrating the sensors and the feedback panel in the textile instead of on top of the textile.
4.	The prototype should be more robust than the existing prototype.
5.	The breathing sensors should be reduced in bulk by integrating the sensors in the textile instead of on top of the textile
6.	The breathing sensors should be produced with industrial scale production methods.
7.	Production steps of the breathing sensors should be reduced.
8.	The haptic feedback panel should be reduced in bulk, by integrating the connection lines in the textile instead of on top of the textile and minimising the connection lines.
9.	The haptic feedback panel should be produced with industrial scale production methods.
10.	Production steps of the haptic feedback should be reduced.

1.3 Description of the structure

The structure of the report is based on APA rules (Poelmans & Severnijnen, 2013). All sections can also be seen in Figure 1. Design Thinking Model. Design thinking is the model used for this study and determined the structure of this report.

In section 1 the problem definition and the design criteria on which this study is based will become clear.

Followed by section 2 in which all the missing information is gathered to start the design process. This happens by means of literature, expert meetings and brainstorm sessions. This gives a clear conclusion on what parameters the product needs to have to fulfil the criteria set in section 1.

Furthermore, in section 3 the design refinement is shown. Based on the conclusion in section 2 all the different samples and tests to abide by these set parameters are shown. Different samples will be produced until good final samples are attained. These 2 samples and the way they are produced are the conclusion of the design refinement.

In section 4 the 2 sample conclusions of section 3 will be combined to make the final prototype of this research. A technical drawing and the final material choice will be explained.

Afterwards, this the prototype will be evaluated and implemented in section 5. Following this a reflection is written on the process and personal process of the author.

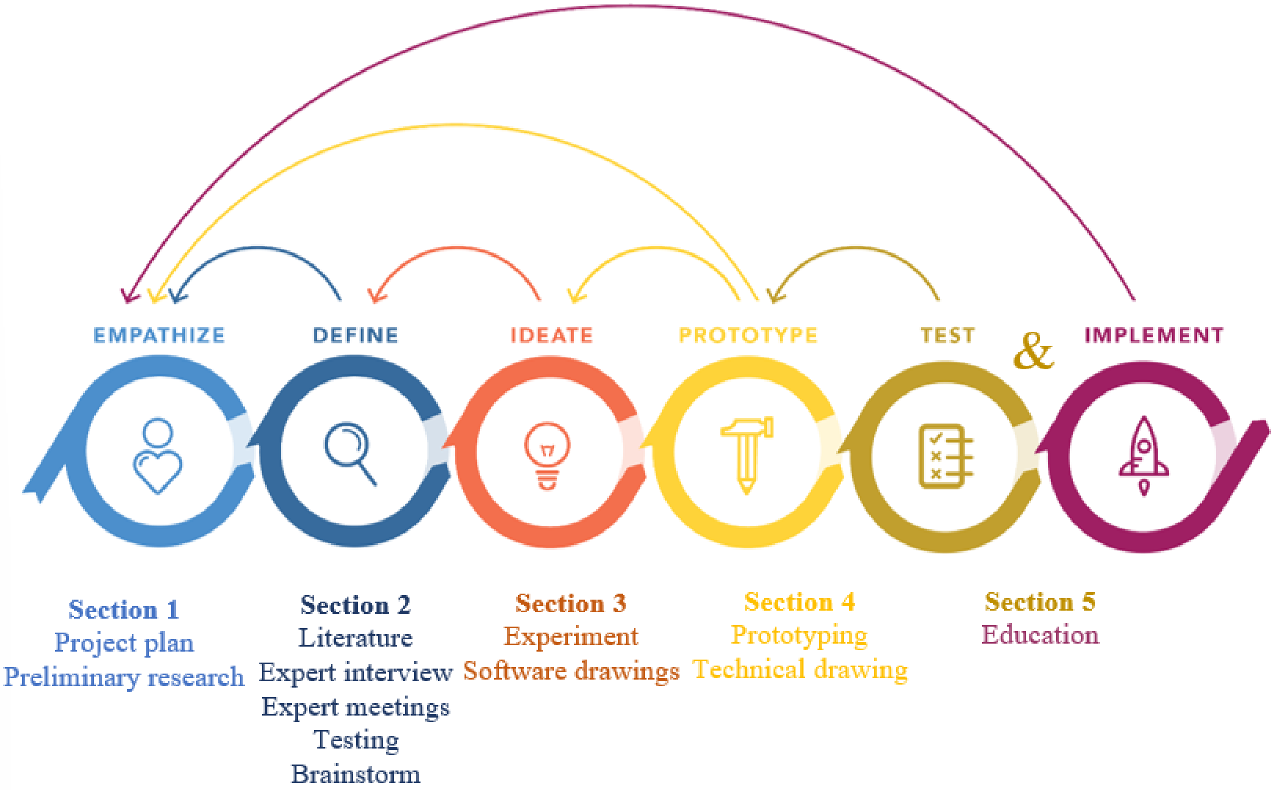


Figure 1. Design Thinking Model

Section 2 Preliminary ideas

2.1 Literature research

A garment with sensors that are worn on the body can monitor different health conditions (Mukhopadhyay, 2014) and is classified as smart textile when it can sense and communicate with the wearer (Cho, Lee, & Cho, 2009). Smart textile garments are used mostly in the medical field because they are good at measuring stress, body temperature, heart rate, muscle motion and other physiological parameters (Mukhopadyay & Tarikul, 2017).

2.1.1 Target group

The WBT is targeted at children aged from 6-12 with dysfunctional breathing. These children frequently have contact with physicians and physiotherapists. Dysfunctional breathing can be multiple breathing disorders. The key symptom is breathlessness after organic causes have been ruled out (Boulding, Stacey, Niven, & Fowler, 2016). Breathlessness can manifest as hyperventilation, deep sighing, air hunger and a lot of yawning.

Children between the ages 6-12 go through some basic cognitive processes; children refine their (earlier developed) perceptual and motor skills. Their attention span becomes better (lengthens), distractions become more controllable and their memory capacity increases (Galotti, 2017). Decision making is a higher cognitive process in the development of a child aged 6-12. Children start to make decisions based on goals they set. The older a child gets, the more complex the goals get. These goals are mainly about school and chores, jobs, hobbies and leisure (Gelderblom & Kotzé, 2008). ‘‘Children of this age group practise understanding, evaluating and solving problems with support when necessary’’ (Siering, 2018).

It’s important for a smart garment to be comfortable if it sits on the skin of these children (Paul, 2014). Although about safety in smart garment for children no reliable research was found. A lot of visible electronics on a smart textile wearable can scare or intimidate children (Ludden, Mader, van Rees, & Siering, 2019).

2.1.2 Knitting

To eliminate this electronic look and make the WBT feel more like a garment, knitting the sensors into the garment would be a good alternative. Circular knitting is the most useful technology for smart textile according to Semnani (2011). For the production of technical textiles, Semnani (2011) views circular knitting as the ideal production method. And within this technology, Stoll and Santoni are the most successful knitting machine brands for smart textiles for healthcare with sensors and knitted sensors (West, 2020).

The S&FT Research group uses Shieldex 78/18 Dtex Z-turns HC+B, 99% pure silver plated polyamide yarn as conductive yarn in a Santoni circular knitting machine. Conductive yarns like this have been used for over 80 years in engineering (Maity, Singha, Debnath, & Singha, 2013). These conductive yarns are used to for example to integrate circuits in textile (Mecnika, Scheulen, Anderson, Hörr, & Breckenfelder, 2015).

2.1.2.1 Santoni circular knitting machine

Figure 2. Santoni SM8-EVO4J

For the sample development in the design refinement of the research the (Figure 2. Santoni SM8-EVO4J) Santoni SM8-EVO4J (single knit) circular knitting machine, available at the Saxion knitting lab, will be used. This machine is fairly new in the lab. Sven Kamphuis from the research group S&FT wrote a machine guide for this machine and showed the author the corresponding software (Kamphuis, 2020).

The Santoni SM8-EVO4J is a single needle bed circular knitting machine, this means that single jersey can be knit but the manufacturing of a R/R, or other 2 bed structures, are not possible.

The machine has an 8 feeder system, which means that yarn is fed from 8 different points in the circle. If the machine has made one rotation then 8 rows are knitted. If more colours need to be added, those 8 feeders will be used as 4 feeders and this will give the option to use up to 5 colours, the knitting process will take 2 times longer with 4 feeders since only 4 rows are knitted in one rotation. For this stage in the WBT project no colours will be added apart from conductive yarn. And thus 8 feeders will be used. But later on the design can easily be adapted and colour can be added.

2.1.3 Embroidering

Another efficient way to integrate the conductive parts in the textile is embroidering (Polenský, et al., 2017). Embroidering makes it possible to integrate various sensors or actuators (motion, acceleration, LEDs, etc.) in your textile (ZSK, 2022).

For the elastic breathing sensors, embroidering would be less attractive since it doesn’t have the same elastic property of the garment as in knitting (Polenský, et al., 2017). But still this method could prove to be successful if the knitting proves to be unsuccessful. Conductive yarns for embroidering are different from those for knitting, since embroidery thread needs to be more sturdy. Conductive embroidery thread is thus mixed with more normal fibres (ZSK, 2022) and has a lower conductivity than a conductive knitting thread. This is why it is hypothesised that knitting will be a better option but embroidering still needs to be included, researched and tested to be sure of this hypothesis.

2.1.4 Safety in smart textiles for children

> ‘‘Safety is the biggest concern for e-textile users because of the fear of electric shocks from the embedded electronics. Even though the embedded electronics are responsible

for the smart behaviour of e-textiles, the safety of the product should not be compromised by the presence of electronic components.'' (Shuvo, Decaens, Lachapelle, & Dolez, 2021)

The safety concern mentioned above is however hard to reassure of its safety within this project. This is because the rules/regulations about smart textiles for children are not there yet. Modint is a branch organisation for textiles that may be able to supply this missing knowledge with tailored advice.

2.2 Product and Material research

2.2.1 Product requirements, Expert interview

Modint is a project partner of the WBT project and a member of the NEN, and they give tailored advice for safety regulations within the textile field. Because in literature information on safety rules for smart textiles for children was hard to find, an expert interview was needed. The interview was also used to get tailored advice about general rules for children's clothing. The transcript of this interview can be found in the Appendices.

The main interview outcome and thus the advice from Modint were; the age group should be changed to 7 till 12 years old, because a product for a 6 year old has stricter rules and thus the product would look different. A lot of effort can be saved if the age group is changed by one year. The closure would be best with a plastic zipper. The shoulder seams should have a Figure 3. Adjustable strap.

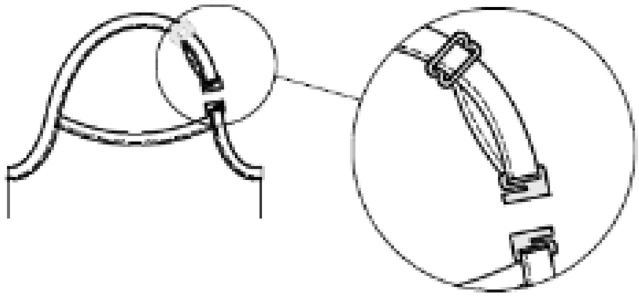


Figure 3. Adjustable strap

The 3D printed battery and PCB box should only be able to open with a screwdriver. This way children won't be able to access it. This advice is given based on toy rules (Geelhoed, 2022). The cables going to this box should be hidden in a textile tunnel on the inside of the vest. Important is that children cannot get stuck behind these cables or are able to pull them out by themselves. With LEDs it is important that it is tested that it doesn't cause epilepsy.

Restriction of Hazardous Substances, Waste of Electrical and Electronical Equipment, Electromagnetic Compatibility and Battery Directive are the pillars for safe smart textile but there aren't any real general smart textile rules published yet (Geelhoed, 2022).

For general smart textile there is ISO/FDIS 24584: Textiles — Smart textiles. In this document it says the amount of current that is allowed to flow in a textile garment. This document however is not published yet. At the end of 2022 this document will be published and it is important that the information published is taken into account for the WBT project.

2.2.2 Material research

2.2.2.1 Expert meeting, breathing sensors

On 17-03-2022 an expert meeting was held for the establishing the parameters of the breathing sensors. The expert in this meeting was Ben Bulsink from Breathpal. He produced the breathing sensors in the existing WBT prototype. Also present in this meeting was Hellen van Rees, the project leader of the WBT and Gemma Ciabattoni, a student from the UT working on the WBT project.

As preparation 3 samples (Table 4. First samples) where produced to show the theory of knitting with conductive yarn. For sensors and actuators a low resistance is needed for them to function correctly. The resistance of the 3 samples were all way too high for the sensors to function correctly. Ben Bulsink mentioned that the Breathpal system works an electric resistance below 7 Ohm, and the sample with the preferred dimensions had an electric resistance of 19.5 Ohm.

Table 4. First samples

0,5 x 60 cm 36. 68 Ω	2 x 60 cm 18.36 Ω	3,5 x 60 cm 12.77 Ω
		

It was concluded that research needed to be done if knitting was a possible option for the Breathpal system; either by means of density, pattern or different yarns. To help with the development of the right pattern design, the reasoning behind the Ohms law was explained by Ben Bulsink. In Figure 4. Theory of Ohms Explained by Ben Bulsink, measuring is done from left to right. The resistance doubles (2 Ohm) if the field gets 2 times as long and is cut in half (0,5 Ohm) when the field gets 2 times as wide.

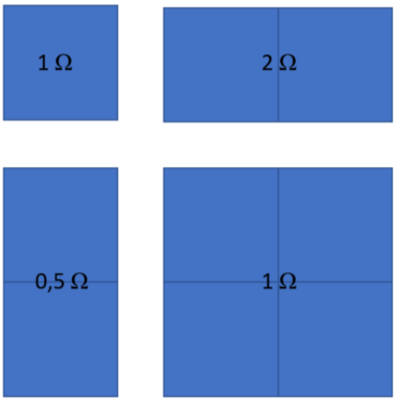


Figure 4. Theory of Ohms Explained by Ben Bulsink

2.2.2.2 Brainstorm

At the start of the brainstorm the functions the grid needs to possess were discussed. The LEDs and vibration motors need to work in serial and be individually controlled. For this a data, ground and power line is needed. It would be ideal if everything can be knitted for easy manufacturing. But it will be a challenge to get the resistance low enough to work. In Figure 5. Series structure, existing prototype is drawn, with a data line, + and – line, as seen in Table 2. Pictures existing prototype. The problem with this is that the line is quite long, which would have a negative effect on the resistance with a knitted structure.

In Figure 6. Series structure, Brainstorm conclusion, a more effective way is drawn. Here it is visible that the + and – lines can take a way shorter route to reach the last LEDs. This would result in a lower resistance and would benefit the result.

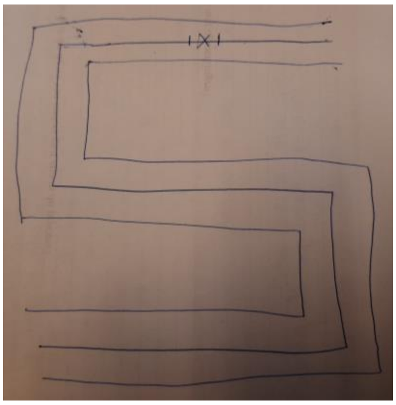


Figure 5. Series structure, existing prototype

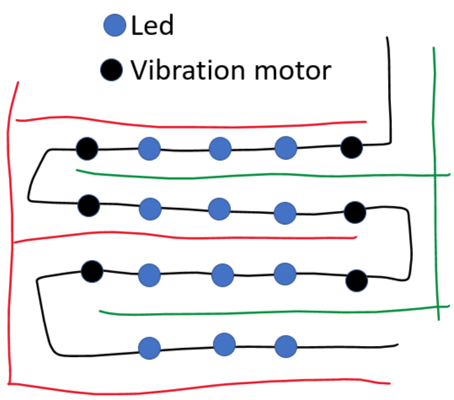


Figure 6. Series structure, Brainstorm conclusion

2.2.2.3 Expert meeting, Feedback panel

With the outcomes of the brainstorm as preparation an expert meeting with Harry Sanderink was done. The main focus of the meeting was discussing and testing if the vibration motors and the neopixel LEDs could function together in series. The functioning in series is of importance for controlling the LEDs and vibration motors individually.

The electronic part of this feedback panel is necessary for the development, however it is outside the knowledge of the author. This meeting was mostly Harry Sanderink and Gemma Ciabattoni, who have the expertise in this subject, testing.

To test this theory a test setup with a breadboard was made. First the code was tested with a neoplixelstrip and a blinking pattern. When the code was working 3 separate led lights replaced the neopixelstrip. This was done to determine the PWM value for certain colours. When those values were obtained, the vibration motor was added, the separate lights were replaced with final LEDs, a transistor was added (amplifies the current because the LEDs need less current than the motor) and a capacitor (10 μF) was added. The circuit was now working and running on 5 volts, the volt level was lowered to 3.3 volts after this (Figure 7. LED and vibration motor on breadboard in series). The circuit was powered by a pc through an Arduino.

It became clear that the motors and LEDs, in theory, can work together in series with 3.3 volts. The next step will be to test this on a knitting structure with the series design in Figure 6. Series structure, Brainstorm conclusion.

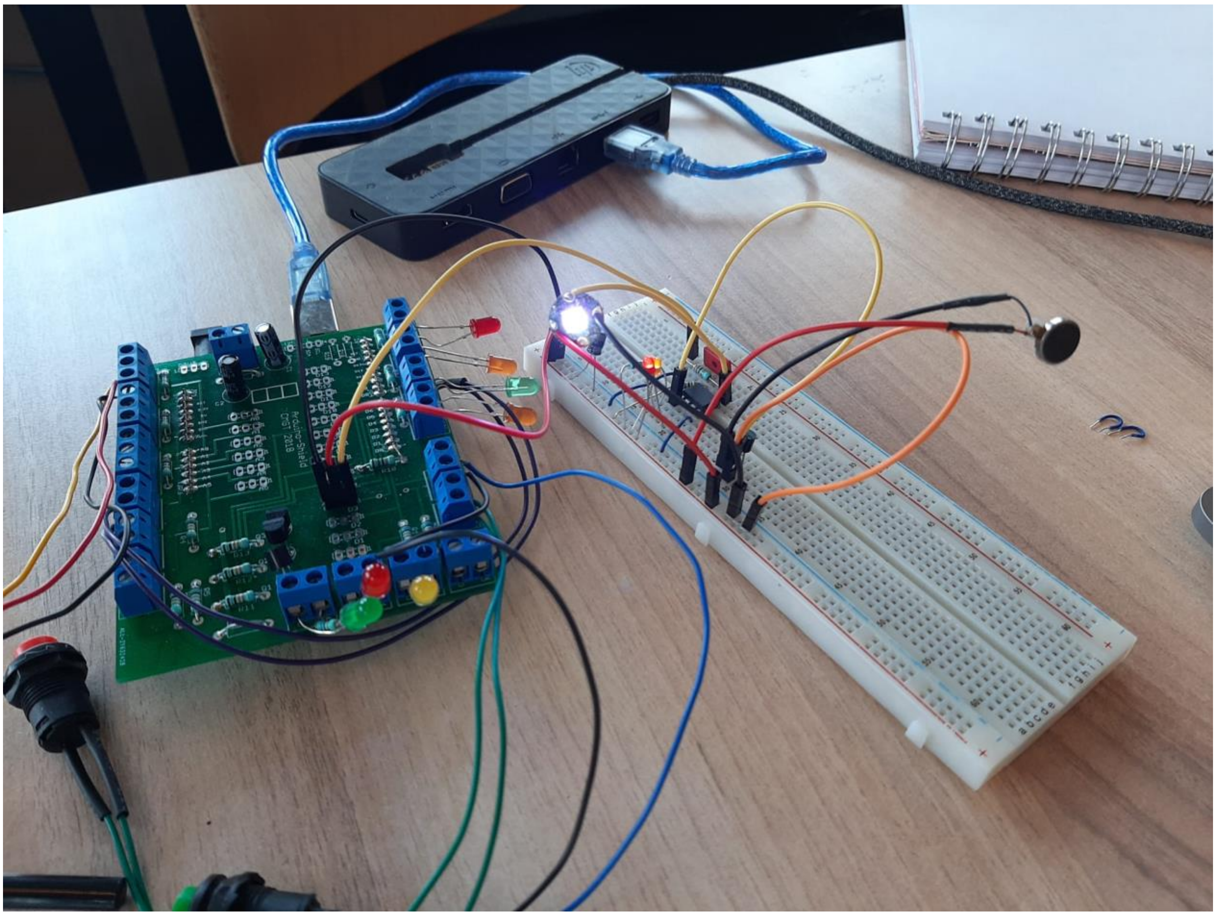


Figure 7. LED and vibration motor on breadboard in series

2.2.2.4 Resistance Testing

In the expert meeting with Ben Bulsink it became clear that a 4 point measuring method was needed for accurate measuring of conductivity in knitted structures.

A normal Multimeter (Figure 8. Systematic Multi Meter setup does not have a known stable current and there is the variable of the wire that can sometimes make the measuring of resistance less accurate. There can be a voltage loss in the cables/clamps, because there is also current going through the same cables/clamps.

The DM3058E from RIGOL is basically a Multimeter however contains more options. This machine can do a 4 wire measuring, which is more accurate than a 2 wire one. With a four-wire measurement there is no voltage loss in the cables/clamps of the voltmeter because there is no current/negligible current flowing in between those cables/clamps and voltmeter. The machine uses stable/known currents. In Figure 9. Systematic 4 point measuring method setup, the setup of this measuring method is drawn.

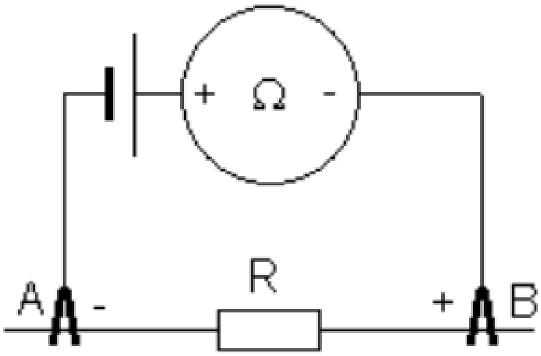


Figure 8. Systematic Multi Meter setup

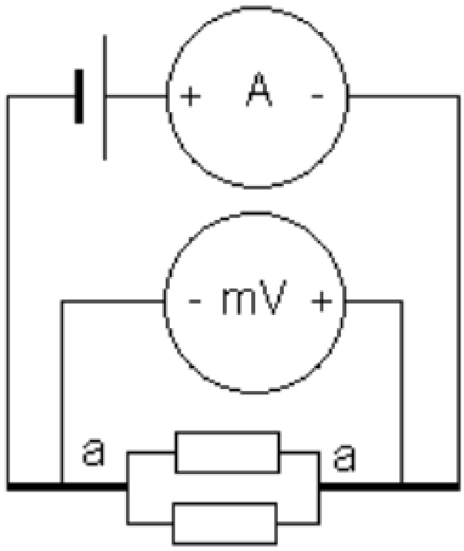


Figure 9. Systematic 4 point measuring method setup

To receive accurate and reproducible results the NEN-EN 16812 norm (NEN-EN 16812 - Textiles and textile products - Electrically conductive textiles - Determination of the linear electrical resistance of conductive tracks , 2016) was followed. An Ohm meter, suitable for four wire measurements, can be used in this norm. This replaces the otherwise needed electrical current source and volt-meter. With the DM3058E from RIGOL the Ohm button needs to be pressed twice to put the setting om 4WR(4 wires) as seen in Figure 10. Picture 4 point measuring method setup.

To eliminate that knitting errors would affect resistance results, 2 conductive tracks with the exact same parameter were knitted for each test. This way there is always a ‘control track’. All samples in this research will be measured this way consistently.

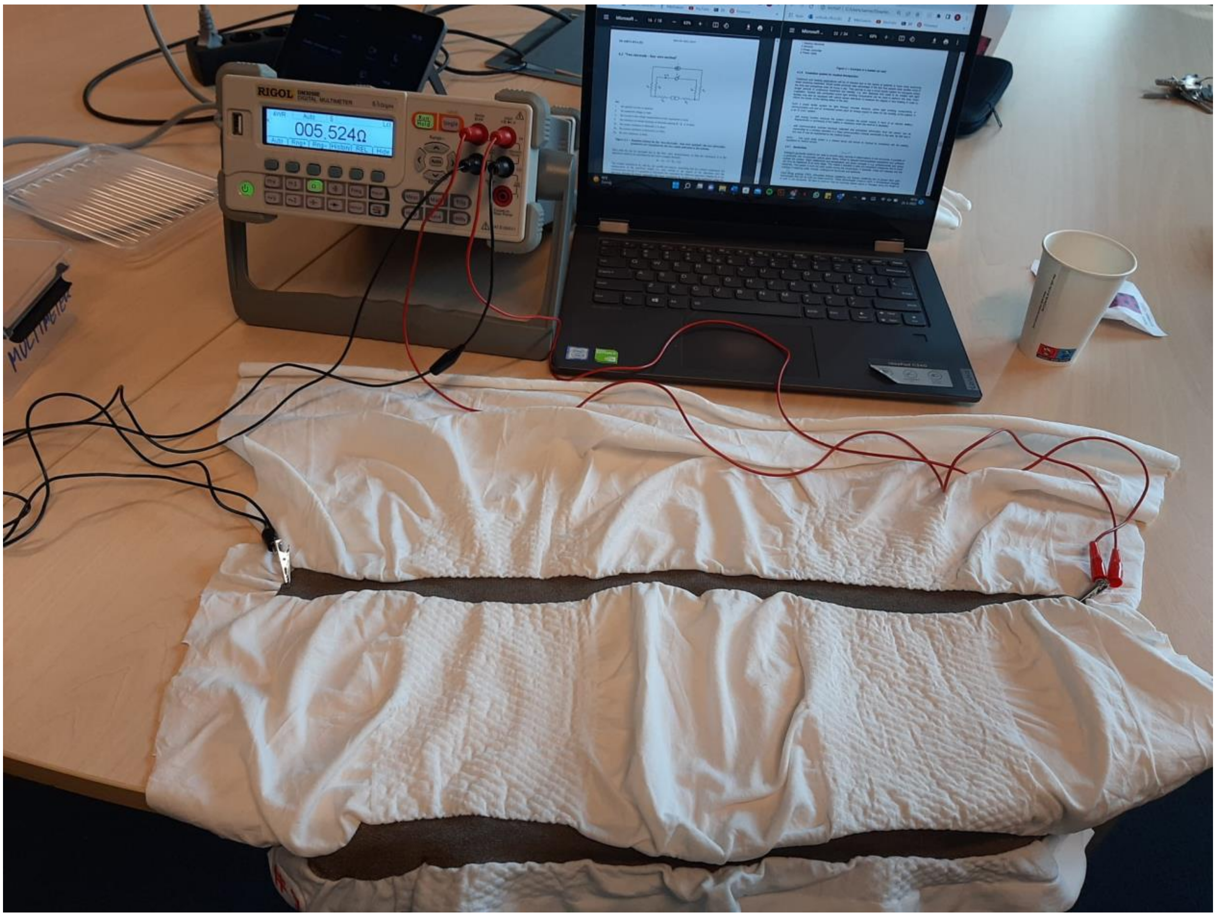


Figure 10. Picture 4 point measuring method setup

2.3 Conclusion

2.3.1 Product rules and regulations

Table 5. Product rules and regulations are based on the interview outcome with Modint (Geelhoed, 2022). All of the topics mentioned in the table below should be kept in mind when designing the final prototype.

Table 5. Product rules and regulations

1	Rules for the age group 7 till 12 years old should be followed
2	Front closure should be a plastic zipper
3	Shoulder straps should be adjustable (Figure 3. Adjustable strap)
4	The 3D printed battery and PCB box should only be accessible with a screwdriver
5	The cables/wires should be hidden by a textile tunnel on the inside of the vest
6	ISO/FDIS 24584: Textiles, Smart textiles, Test method for sheet resistance of conductive textiles using non-contact type. (future research)

2.3.2 Breathing sensors

The breathing sensors of the WBT should be integrated into the main layer of the vest. This should be done by knitting the body of the vest with 2 conductive tracks; one at the abdominal and one at the breast. The knitted track should have a resistance below at least 13 Ohm, but the lower the better. The size of these tracks should be around 60 CM long and 2 CM wide, this way the exact location of the elastics in the existing protype will be replaced. By means of knitting experiments with different structures, densities or designs this should be achieved.

2.3.3 Feedback panel

The feedback panel of the WBT should be located behind the main layer of the vest in the abdominal area. The optimal layout for this panel should be based on Figure 6. Series structure, Brainstorm conclusion. This contains 12 neopixel LED light and 6 vibration motors.

The size of the panel measured from the LEDs on the most outside corner should be around the same size as that of the existing prototype feedback panel. It would also be preferable if the textile panel would be somewhat thick and stable to protect the electronics and prevent them from moving too much. The connection points of the electronics should be integrated in the textile by means of knitting with conductive yarn.

The LEDs and vibration motors should work in series and be individually controlled. To realise this on the knitted panel this means making a prototype version of a PCB with all the components of Figure 7. LED and vibration motor on breadboard in series. The right resistance for the knitted textile panel with conductive yarn cannot be determined without making a test setup and thus the information will become clear in section 3.

The way the feedback panel is designed it is easy to adjust the design later on in the WBT project. The LEDs and vibration motors can be moved anywhere along the data line and still work correctly. This is good because there is still research being done to haptic feedback by means of vibration motors. The first conclusion of this research leads to 6 vibration motors in this set up but this may change later on in the research. This is why it is good that the design is slightly flexible for further development.

Section 3 Design refinement

Section 2 had 3 main conclusions, namely; 2.3.1 Product rules and regulations, 2.3.2 Breathing sensors and 2.3.3 Feedback panel. Product rules and regulation are important for this project, but more important at this stage (the beginning) of the project, is well integrated technology in the prototype such as the breathing sensors and the feedback panel. The product rules and regulations will become more important once the technology is integrated and working, more towards the end of the project. This is why for now the product rules and regulations are put aside in this section of the research. This will help to focus on the main scope of the research which is integrating the technology.

3.1 Santoni circular knitting machine process

Following is an overview of the design process with software for the santoni circular knitting machine

3.1.1 .Pat File

The first software program needed to make designs for the machine is Photon. To start off the design process, the pattern must be drawn and saved as a .pat file. Because in all the produced samples for this research 1/ 2 colours are used the 2 colour pattern system will be explained (Table 6. Yarn finger functions, 8 feeders/ 2 colours). In this Table 6. Yarn finger functions, 8 feeders/ 2 colours, the function of the colours in the pat. File can be seen. Basically a pat file is a grid with the repeat of a pattern. With a RL in one colour it will look like one square, but if a mix of colours are used, or a mix of colour with a float of a miss, the pattern will look like a grid. All the combinations are possible to draw, but with floats and misses it can become harder to knit. Since it is not possible to just miss or float.

If a simple R/L (single jersey) in the plain yarn is desired, the .pat file will look like this (Figure 11. Mint.pat). When this is desired in a different colour, the .pat file will look eighter purple or white. If a knit with colour 1 and every other stitch a miss is desired the pattern will look like this (Figure 12. 1x1MissPurple.pat) or a repeat of this pattern.

Table 6. Yarn finger functions, 8 feeders/ 2 colours

2 colors	
	Plain
	Miss
	Float
	Color 1 (Conductive yarn)
	Color 2

Figure 11. Mint.pat

Figure 12. 1x1MissPurple.pat

3.1.2 .Sdi File

Photon is also needed to draw a .Sdi file. The file is for the design of the knitting sample. Within this program it is very important that no colours are used that have a function. Colour like the ones seen in (Table 6. Yarn finger functions, 8 feeders/ 2 colours) and colours for the extra colours that are not in use in this research. Because if one of those colours are used, the machine will read the function of those colours. So with all the leftover colour the design is drawn.

The drawing process is quite similar to drawing in the well-known program Paint. In (Figure 13. Example .Sdi) an example .Sdi drawing is shown. Important to note is that the drawing is upside down. This is needed if a welt is desired at the bottom of the garment, because the welt is always produced at the start of the process. All the colours used in (Figure 13. Example .Sdi) don't have a different function and mean nothing, these colours are purely there to indicate shapes in the design. In the next step of the process a function is assigned to these shapes and the colours will change. The cutting lines for the manufacturing process are drawn as well, this will make the cutting easier.

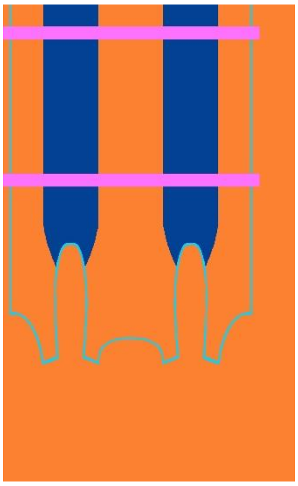


Figure 13. Example .Sdi

3.1.3 .Dis File

When the .Sdi file has the full design it is converted to a .Dis file. When converting all the colours in the .Sdi file are given a .pat file. Here (Figure 13/Figure 14) you can see the orange colour has been replaced by (Figure 11. Mint.pat) pattern. So the main fabric will be knitted with the plain yarn. The cutting lines and the dark blue parts have been given a rib binding. Rip is created by knitting (with plain yarn) and miss stitches. This is why it looks black (miss) with green (plain). These functions can be found back in Table 6. Yarn finger functions, 8 feeders/ 2 colours. Pink has been given a purple .pat file and will be knitted as an R/L with conductive yarn (colour 1). With the .Dis file, the bindings and the location of those bindings can be seen in one clear drawing. However when made smaller it is not so clear anymore. For a clear overview a small .Dis drawing has been added of all samples throughout the development. For a more closeup look at the binding the .Dis drawing of all samples can be found in Appendices.

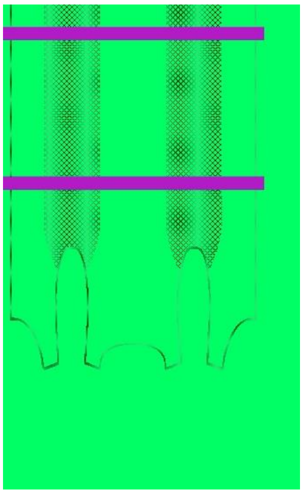


Figure 14. Example .Dis

3.1.4 .Chain File

When the .Dis file has all the right patterns assigned it can be added in a chain file. The welt will also be added in the chain file, and this is how it will be combined.

‘‘Within the CHAIN file all the functions and instructions for the machine can be seen step by step. The CHAIN file is made to program the specific parts of the machine with a specific function, to create a piece of fabric with the exact design that’s made for the use of the body and/or the welt. The program D3p can be used to open a CHAIN file you want to use, the CHAIN file will open in the program Quasar.’’ (Kamphuis, 2020)

Within the chain file it is important that all the yarn fingers needed for the design are switched on at the start and off at the end. Also important is that the full .Dis file is visible, if not the economizer must be increased. When these parameters are set, the chain file can be used for producing similar samples as well, only the .dis file needs to be updated.

3.1.5 The machine

When the chain file is ready it is uploaded to a USB stick and this stick is inserted in the knitting machine. For this research the conductive yarn is needed so it is important that this yarn is in treated correctly in yarn finger 7. When knitting with conductive yarn it’s important to stay with the machine during the knitting process. Since conductive yarn is smooth and thin it is common for the machine to give some errors, that are easily fixed if the machine is being observed during the knitting. Especially with the float and miss structures with conductive yarn, good observation is important. When done with knitting, the sample comes out of the machine and needs to be steamed to crimp to the final size.

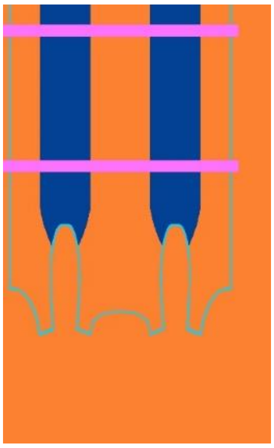
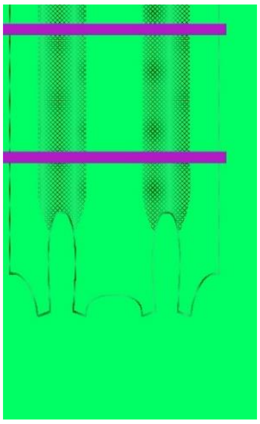
3.2 Breathing sensors (including Software drawings)

All the .Dis drawings of the samples mentioned in this chapter can be found enlarged and clear in the Appendices. Circular knitting will be used to make different samples, based on the finding of different methods and tests these samples will be made and chanced. The focus will be on knitting the breathing sensors, with the right resistance. The resistance will be measured for all samples in the correct way according to experts.

If conductive tracks are mentioned in the text below, what is meant is a row with conductive knitted yarn. These tracks are numbered starting from 1 for each sample. The length and width per sample is described with rows and needles, what is put into the software, and in CM. The CM values are obtained by measuring the knitted sample after steaming, flat on the table without stretching.

The first sample (Table 7) for this research was produced based on the existing prototype. The pattern of the vest and structure below the armpits is the exact same as that on the existing prototype. The placement and size of the conductive tracks are the same size and in the same place as the breathing sensors from Breathpal in the existing proto type. This placement has been researched and proven (Ludden, Mader, van Rees, & Siering, 2019). As seen in Table 7, a simple RL structure is used for the conductive part. When measured with the 4 points measuring system the resistance was 18.36 Ω. This sample was made in preparation of the expert meeting with Ben Bulsink and it became clear that this resistance was way too high to work with the Breathpal system.

Table 7. Parameters Sample #1

Sample picture	.Sdi
	
	.Dis
	

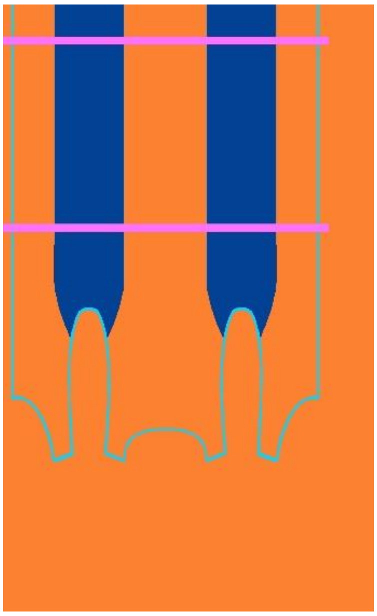
Conductive track #	1&2
Length in Needles	1181
Length in CM	58
Width in rows	60
Width in CM	2
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	18.36 Ω

The second sample (Table 8) produced for this research is almost the same as Table 7. Parameters Sample #1. The only difference is that half the amount of rows of conductive yarn are knitted. The resistance is also almost double that of the first sample. Namely 36. 68 Ω (Table 8), this indicates Figure 4. Theory of Ohms Explained by Ben Bulsink is roughly applicable for knitted surfaces with a RL structure. This sample was made in preparation of the expert meeting with Ben Bulsink and it became clear that here too the resistance was way too high to work with the Breathpal system.

Table 8. Parameters Sample #2

Sample picture

.Sdi



Conductive track #	**#1&2**
Length in Needles	1181
Length in CM	58
Width in rows	30
Width in CM	0.5
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	36. 68 Ω

.Dis

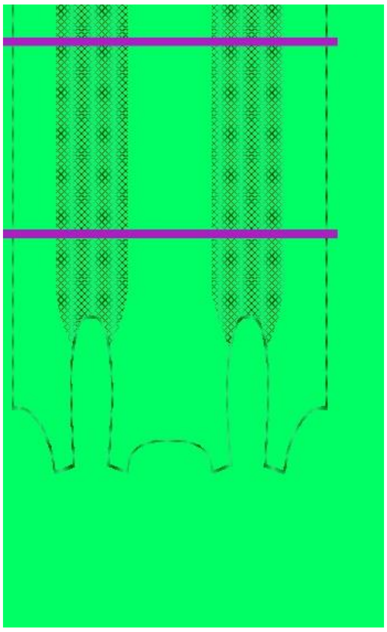
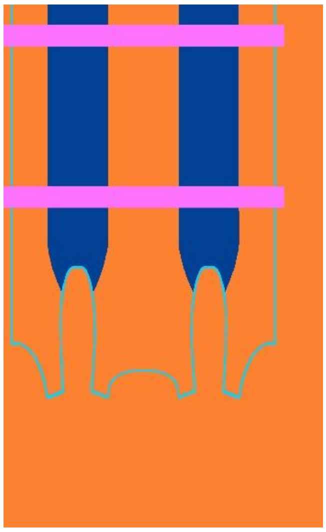


Table 9. Parameters Sample #3 was produced in preparation for the expert meeting with Ben Bulsink. This sample has the lowest resistance of the first 3 samples because the amount of rows is the highest. This proves that the resistance gets lower if more rows are added. Figure 4. Theory of Ohms Explained by Ben Bulsink indicates the same only the ohm value is not cut in half as seen in here. This indicates that the theory is applicable on knitted structures, but it cannot be expected to be very accurate and used for calculating. It is however an interesting principle to keep in mind when developing the next sample. This resistance, namely 12.77 Ω (Table 9) also proved to be too high to work with the Breathpal system. Furthermore, the conductive tracks take up a lot of space in the vest and this is moving away from the preferred design.

Table 9. Parameters Sample #3

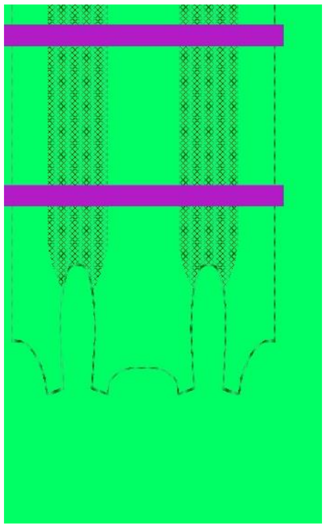
Sample picture

.Sdi



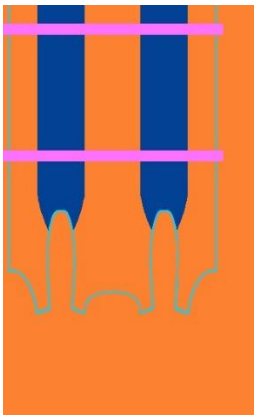
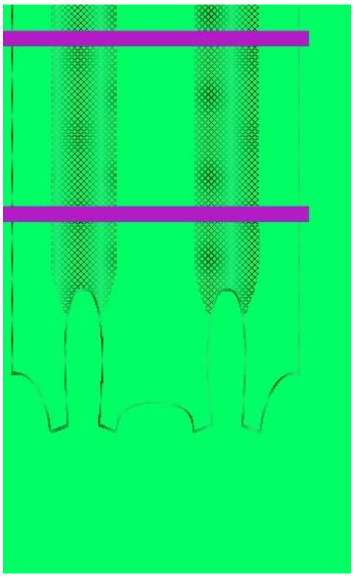
Conductive track #	**#1&2**
Length in Needles	1181
Length in CM	58
Width in rows	90
Width in CM	3.5
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	12.77 Ω

.Dis



The top of Table 10. Parameters Sample #4 is missing because something went wrong with the knitting machine in that part, but that was not important for the design development so the sample is still usable for this research. The sample had the exact same .Sdi and .Dis file as Table 7. Parameters Sample #1. But in the chain file some chances were made to the density of the conductive tracks. The tracks were made more dense to test if this would have a good influence on the resistance. The resistance however barely changed compared to sample 1(Table 7. Parameters Sample #1/Table 10. Parameters Sample #4). And thus density changes were put aside for future samples because of lack of relevance for the project. Another reason that this was put aside is because the tracks already pull at the base fabric (white). If this density was to decrease more, it would have a negative effect on the fit of the garment.

Table 10. Parameters Sample #4

Sample picture	.Sdi
	
	.Dis
	

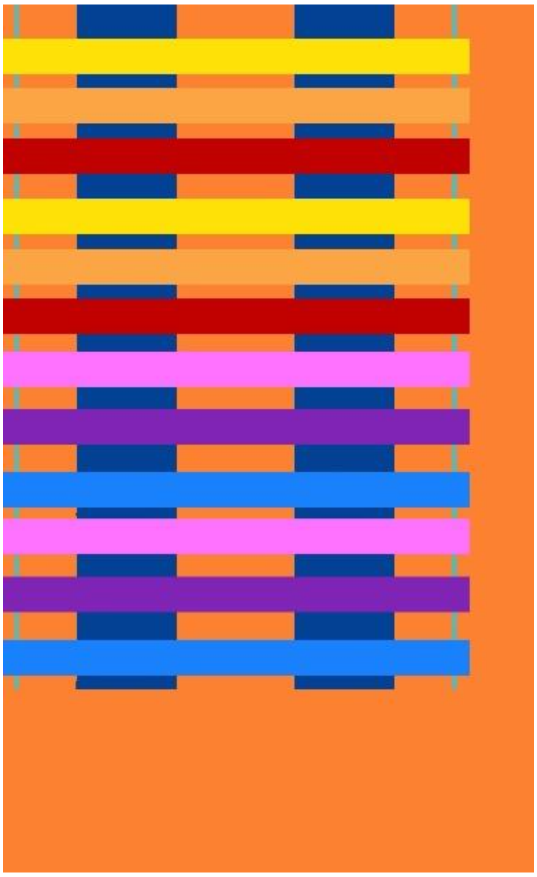
Conductive track #	**#1&2**
Length in Needles	1181
Length in CM	55
Width in rows	60
Width in CM	2
Density (software value)	80
Pattern used for conductive yarn	
Resistance in Ohm	21.63 Ω

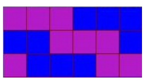
Because the resistance was way too high in all the previous samples, there was a need for different sample manufacturing. In Table 11. Parameters Sample #5, 12 conductive tracks where knitted. Because a lot of different bindings were desired in this sample, a lot of different colours were used in de .Sdi drawing. Every track has a corresponding track that has the exact same parameters to make sure the resistance testing was accurate. Existing float and miss binding in the Saxion database where used for the .Pat files in sample #5 to see what this would mean for the resistance.

Track 1 to 6 (Table 11. Parameters Sample #5) are made with float bindings and this resulted in big loops at the backside of the fabric. This could be very interesting for skin contact sensors but for this research it was not as relevant because these loops mean longer conductive yarn that were used. And in theory shorter yarn would be better for the resistance.

In track 7 to 12 (Table 11. Parameters Sample #5) different miss bindings were used. These bindings pulled the fabric together quite dense in some cases which is an interesting observation. Also miss stitches make fewer loops than a simple RL structure as used in the previous samples. This means that shorter yarn is used to knit the same width as with an RL structure. Shorter would mean lower resistance according to Figure 4. Theory of Ohms Explained by Ben Bulsink. And thus this explains why exploring different miss structures may be beneficial for this research.

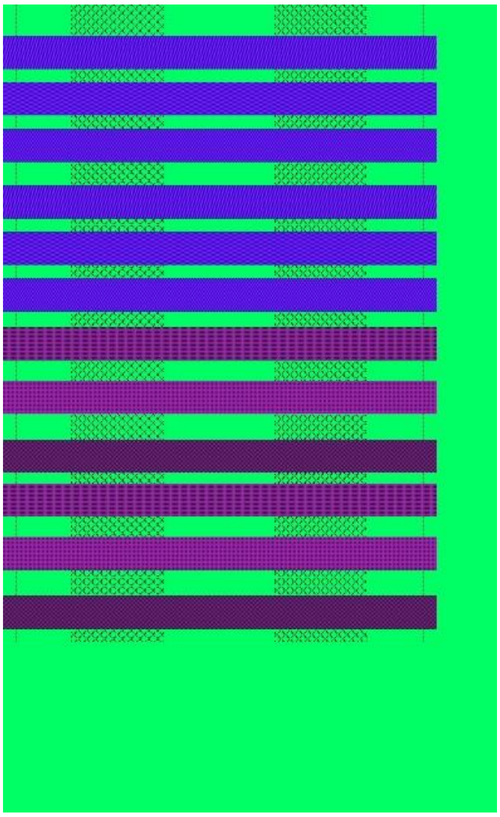
Table 11. Parameters Sample #5

Sample picture	.Sdi
	

Conductive track #	**#1&4**
Length in Needles	1181
Length in CM	54
Width in rows	90
Width in CM	2.5
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	15,23 Ω
Conductive track #	**#2&5**

Length in Needles	1181
Length in CM	53
Width in rows	90
Width in CM	2.3
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	16.84 Ω
Conductive track #	**#3&6**
Length in Needles	1181
Length in CM	52.5
Width in rows	90
Width in CM	2.5
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	15.92 Ω
Conductive track #	**#7&10**
Length in Needles	1181
Length in CM	50,5
Width in rows	90
Width in CM	1.8
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	12.85 Ω
Conductive track #	**#8&11**
Length in Needles	1181
Length in CM	51
Width in rows	90
Width in CM	2.3
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	12.33 Ω
Conductive track #	**#9&12**
Length in Needles	1181
Length in CM	50
Width in rows	90
Width in CM	1.4

.Dis



Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	12.95 Ω

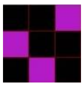
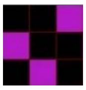
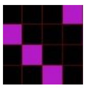
Table 12. Parameters Sample #6 was designed based on the findings of Table 11. The more black in the .Pat file, the more miss stitches are in the knitted structure. These structures were not found in the Saxion database and designed as an experiment by the author for this specific research. To test Figure 4. Theory of Ohms Explained by Ben Bulsink and to get a resistance as low as possible, 12 conductive tracks were knitted. From every used structure 2 widths tracks are used to check if the resistance would be half if 2 times the amount of rows are used. And this ended up becoming roughly true which once again indicates the theory is pretty accurate for knitted structures.

The theory is the shorter and wider the track, the lower the resistance will be. But it is also important that the final dimensions will be similar to that of Table 7. Parameters Sample #1 because this fits with the preferred design (Ludden, Mader, van Rees, & Siering, 2019). So with this in mind track #11&12 (Table 12. Parameters Sample #6) prove to be the right structure. And the resistance is low enough to work with the Breathpal system. Basically the structure is missing 3 times for every knitting loop that is made. Which means the yarns used shortest compared to all the other structures used in this research. Furthermore this binding shrinks 180 rows in the same dimensions as 60 rows with a normal RL structure (Table 12. Parameters Sample #6 vs. Table 7. Parameters Sample #1). This means that even though the track had the roughly same dimensions in CM as Sample #1, the knitted structure is shorter (shorter yarns) and wider (more rows). With this the author has proven that Figure 4. Theory of Ohms Explained by Ben Bulsink is roughly applicable for knitted conductive fabrics. As well as found the ideal structure to knit the breathing sensors.

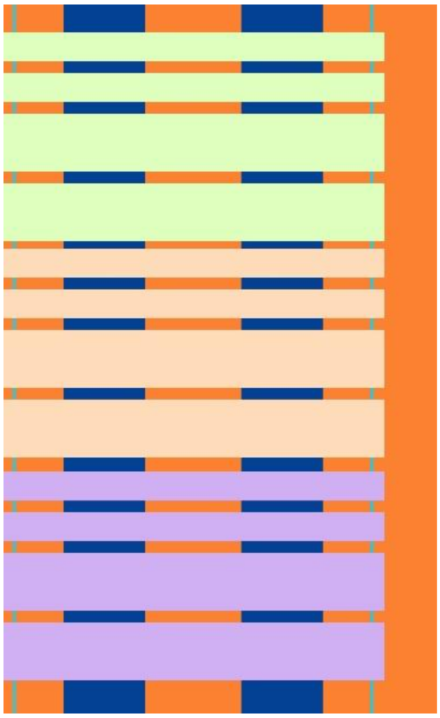
Table 12. Parameters Sample #6

Sample picture

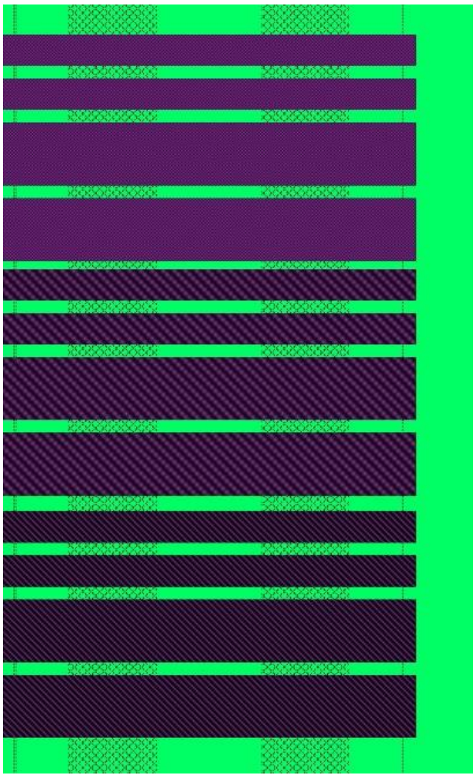
Conductive track #	**#1&2**
Length in Needles	1181
Length in CM	50

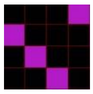
Width in rows	90
Width in CM	1.4
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	13.05 Ω
Conductive track #	**#3&4**
Length in Needles	1181
Length in CM	52
Width in rows	180
Width in CM	3.3
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	6.98 Ω
Conductive track #	**#5&6**
Length in Needles	1181
Length in CM	49
Width in rows	90
Width in CM	1
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	11.18 Ω
Conductive track #	**#7&8**
Length in Needles	1181
Length in CM	49
Width in rows	180
Width in CM	2.1
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	5.21 Ω
Conductive track #	**#9&10**
Length in Needles	1181
Length in CM	45.5
Width in rows	90
Width in CM	0.7
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	9.79 Ω
Conductive track #	**#11&12**
Length in Needles	1181

.Sdi



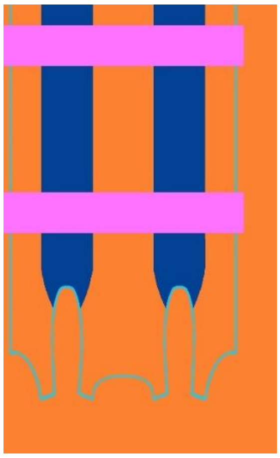
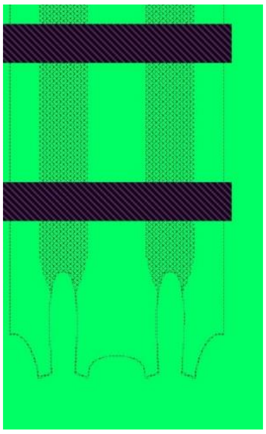
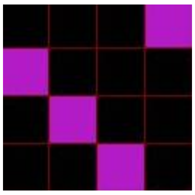
.Dis



Length in CM	45.5
Width in rows	180
Width in CM	1.6
Density (software value)	110
Pattern used for conductive yarn	
Resistance in Ohm	5.18 Ω

Based on Track #11&12 of Table 12. Parameters Sample #6 the sample seen in Table 13 was produced. The width of the tracks were increased to 200 to really get the same width as Sample #1.

Table 13. Parameters Sample #7

Sample picture		.Sdi
		
		.Dis
Conductive track #	#1&2	
Length in Needles	1181	
Length in CM	50	
Width in rows	200	
Width in CM	2	
Density (software value)	110	
Pattern used for conductive yarn		
Resistance in Ohm	5.02 Ω	

3.3 Feedback panel (including Software drawings)

All the .Dis drawings of the samples mentioned in this chapter can be found enlarged and clear in the Appendices.

Knitting integration

Here all the samples and design steps can be found about the feedback panel. Important for the feedback panel development is the loops on the backside of the fabric. This could bring contact in between the -, + and data line. To make sure this does not happen all the loops at the backside of the fabric are cut after steaming the samples.

The layout as drawn in Figure 6. Series structure, Brainstorm conclusion, was drawn in the knitting software and Table 14. Sample #2.1 was the outcome of this first design.

Table 14. Sample #2.1

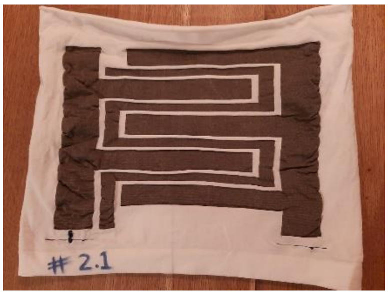
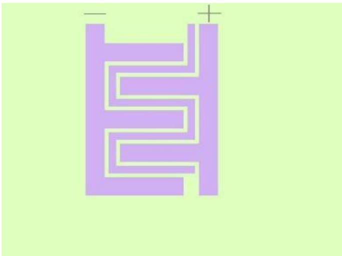
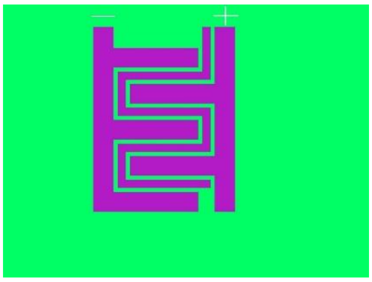
Sample picture	.Sdi	.Dis
		

Table 15. Sample #2.2is almost identical to the previous sample but some openings are made in the + and – line to save some conductive yarn.

Table 15. Sample #2.2

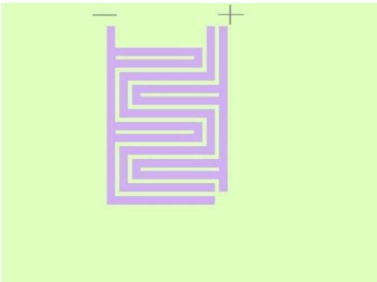
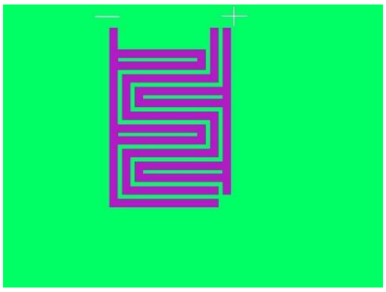
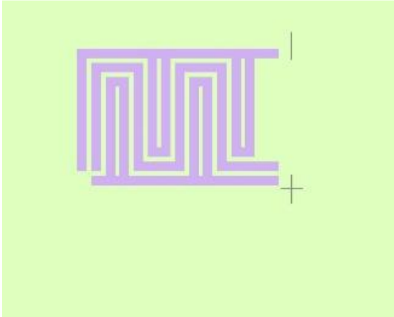
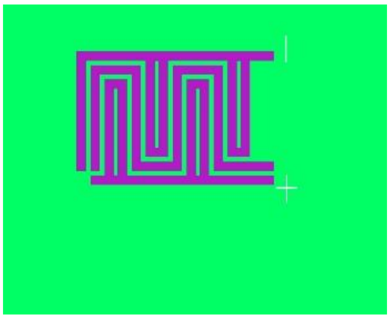
Sample picture	.Sdi	.Dis
		

Table 16. Sample #2.3 was made to see if it would benefit the design of the feedback panel if it was knitted sideways instead of lengthways like the samples before. This was however not the case since the tracks are longest going from right to left (or the other way around). Since the rows of yan are cut the length ways. The lower resistance comes from the uncut yarn tracks. The optimise the most of these tracs, the sample should be knitted the direction of Sample #2.1 and #2.2 and not like #2.3.

And thus knitting the design sideways will now not be developed further because it does not benefit the design in any way.

Table 16. Sample #2.3

Sample picture	.Sdi	.Dis
		

Because the knitted fabric in the previous fabrics didn't feel very thick or stable, what is needed (based on 2.3.3 Feedback panel) a different binding was given to the fabric. Figure 15. 3x3 PurpleMiss.Pat was given to the conductive tracks in Table 17. Sample #2.4. A variation of this pattern (the same but then with mint, so plain yarn instead of conductive) was given to the body (white part) of the fabric.

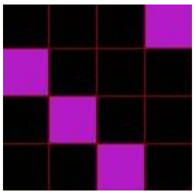
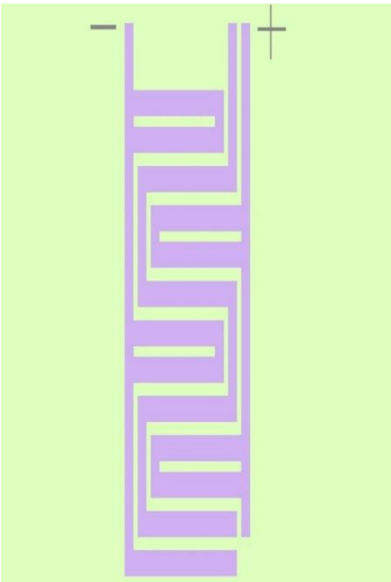
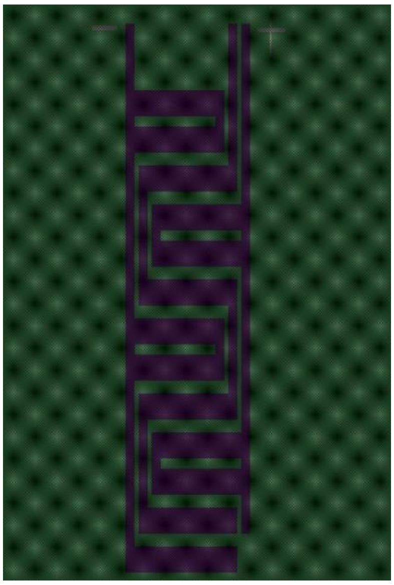


Figure 15. 3x3 PurpleMiss.Pat

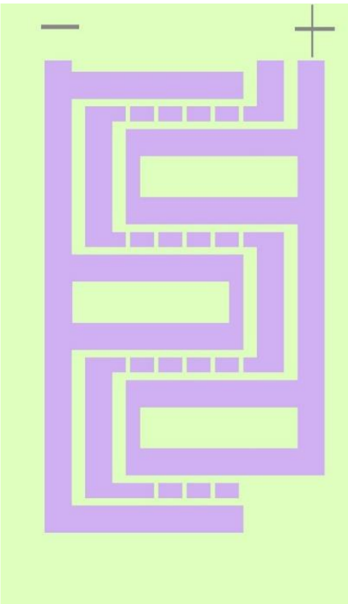
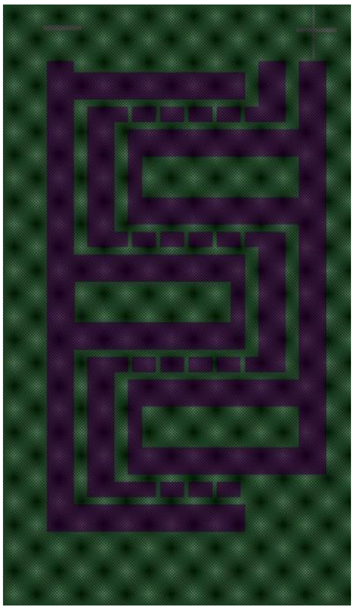
Table 17. Sample #2.4

Sample picture	.Sdi	.Dis
		

In Table 17. Sample #2.4 the data line was slightly too big to be covered by the desired LEDs. Based on the size of the LEDs the data line was made a bit thinner and the space from the data line to + or – was also reduced in Table 18. Sample #2.5. This thinning of the conductive track will add to the resistance and to compensate for this the vertical lines of the design were made wider to compensate and reduce resistance.

Table 18. Sample #2.5 has the design of Figure 6. Series structure, Brainstorm conclusion. This means there is space for 12 LEDs on the middle and 6 vibration motors on the outside of the design. For now however it is not possible to test this sample with all the vibration motors and LEDs on it because the prototype versions of the PCB for the vibration motors were not ready yet. This is done by Gemma Ciabattoni, another student involved in the WBT project.

Table 18. Sample #2.5

Sample picture	.Sdi	.Dis
		

LEDs and Vibration motor integration

When the prototype PCBs for the vibration motors were in development the measurement of the PCB were sent to the author. For testing 2 of these PCBs were produced (Table 20. PCB with vibration motor). If the test works then smaller scale PCBs with vibration motors can be ordered to be produced for the project in the future.

Because only 2 vibration motors can be tested the author made sure to include 12 LEDs. This way at least all the LEDs can be tested at once. 12 LEDs is the final and desired amount, it is not final placement. In Table 19. Sample #2.6 those 12 LEDs are visible. These LEDs were attached by hand sewing with conductive yarn (see closeup in Table 19).

Test the first 9 LEDs on knitted fabric the ground (-) power (+) and data in were connected with an Arduino. Gemma Ciabattoni hooked this sample up with power and a simple code with a blinking pattern and some different patterns. The sample worked and the first 9 LEDs were controlled individually (last 3 LEDs were separated by the data line so where not able to be tested yet).

Gemma Ciabattoni handmade 2 prototype PCBs seen in Table 20. These PCBs have all the components as seen in Figure 7. LED and vibration motor on breadboard in series. However this was made more compact.

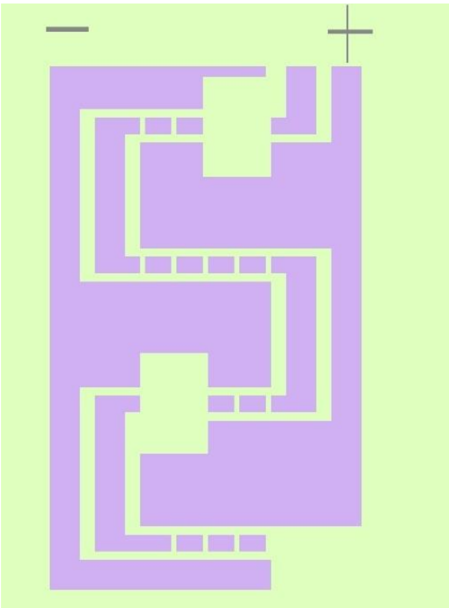
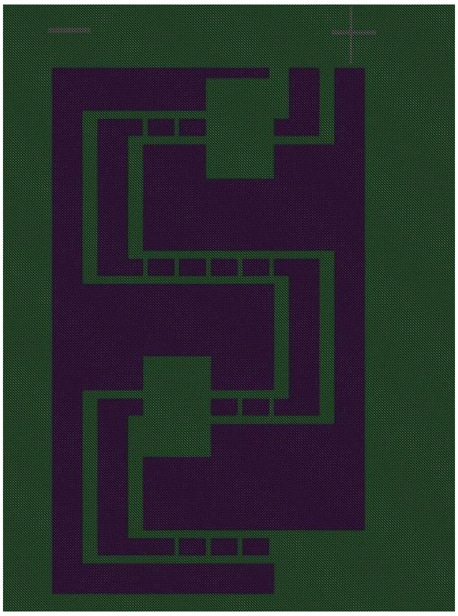
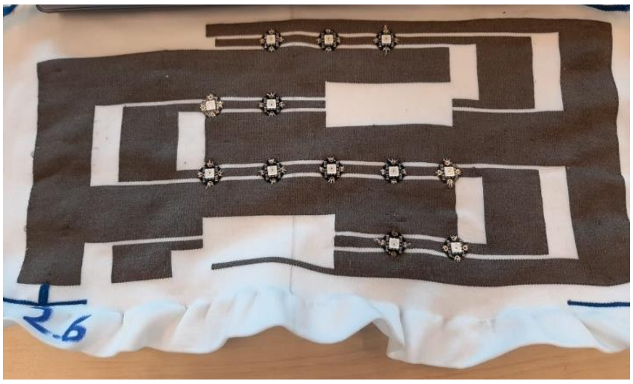
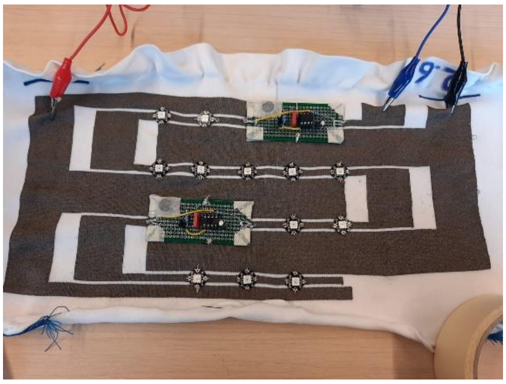
The PCBs were attached to the sample with the LEDs. These 2 PCBs connected the whole data line and the sample was ready to be tested.

The ground (-) power (+) and data in cables connected the fabric with an Arduino. Gemma Ciabattoni hooked this sample up with power and a simple code with a blinking pattern and some different patterns. The sample worked and the LEDs and motors where controlled.

However some connections were not so stable when the fabric was moved. When the fabric was stretched or unstretched some led turned off and the intensity of the vibration motors changed. There are a few speculations as to why these problems occur. To solve these problems the cause of the unstable connections must be known and more research needs to be conducted. Recommendation for these subjects will be mentioned in section 5.

Testing Table 19. Sample #2.6, has proven that the LEDs and vibration motors can work together in series on a knitted textile panel the same way as in Figure 7. LED and vibration motor on breadboard in series with 12 LEDs and 2 vibration motors.

Table 19. Sample #2.6

.Sdi	.Dis
	
with LEDs	with LEDs and motors
	

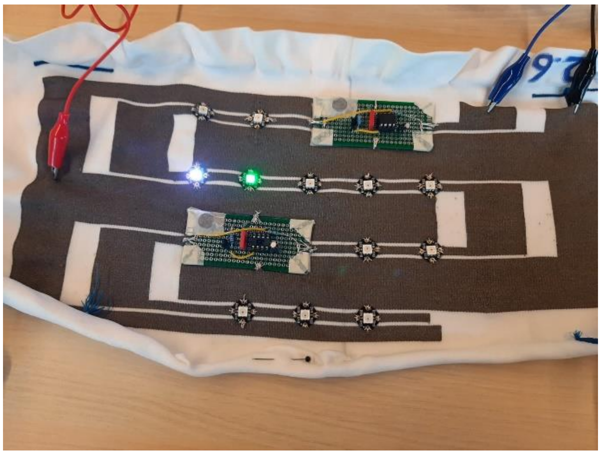
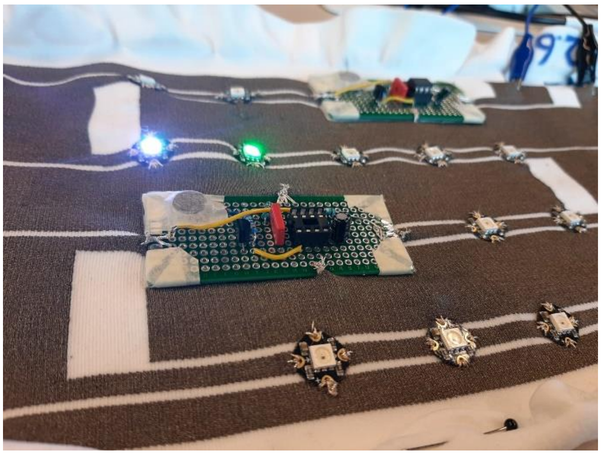
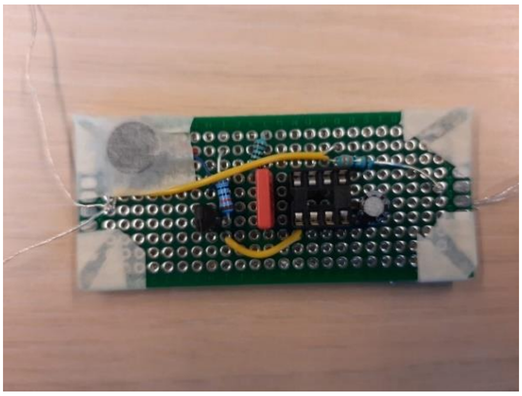
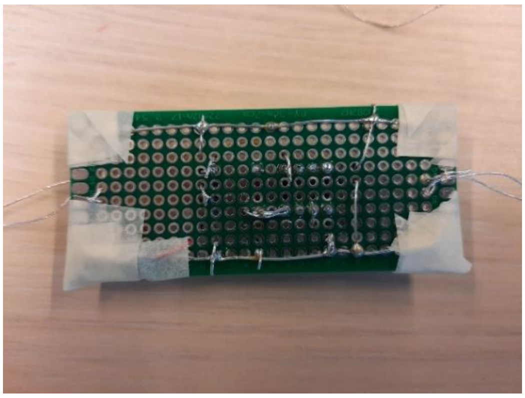
with LEDs and motors with power	with LEDs and motors with power, close-up
	

Table 20. PCB with vibration motor

Front	Back
	

3.4 Conclusion

3.4.1 Breathing sensors

Based on the research done on knitted breathing sensors, the following conclusions can be drawn; Sample #7 is the best sample based on the resistance.

Although the width in CM (Table 21. Comparison Sample #1 and Sample #7) is roughly the same, the width in rows increased from 60 to 200. Which means lower resistance according to Figure 4. Theory of Ohms Explained by Ben Bulsink.

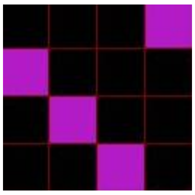
Also the length of one yarn within those 1181 needles is shorter in sample #7 compared to that of sample #1. This is because for every 4 loops that are made in sample #1 only 1 loop is made in sample #7. Making less loops will result in a shorter yarn, which results in a lower resistance according to Figure 4. Theory of Ohms Explained by Ben Bulsink.

The overall resistance from sample #1 to sample #7 dropped from 18.36 Ohm to 5.02 Ohm, which is below the allowed 7 Ohms for the breathing sensors. The drop of this resistance is substantiated by; literature, Ben Bulsink (a sensor expert) and the tests done for this research. With these 3 topics triangulation is applied over the breathing sensors conclusion.

An exact replica of Table 13. Parameters Sample #7 has been sent to Ben Bulsink to test with the Breathpal system. The results of the first tests can be found in the Appendices. It shows very promising results. The conclusion of the tests are: The adapted Breathpal electronics allow for straps up to 20 Ohm total resistance (more than initially expected). The noise on the reading may increase by such higher resistances, compared to i.e. 6 Ohm, but further study and tests may reduce the noise at higher resistances (Appendices).

This entails that that with the resistance that Sample #7 has the Breathpal system work without the increase in noise. And thus works correctly, based on Ben Bulsink's findings.

Table 21. Comparison Sample #1 and Sample #7

Sample #	**1**	**7**
Length in Needles	1181	1181
Length in CM	58	50
Width in rows	60	200
Width in CM	2	2
Density (software value)	110	110
Pattern used for conductive yarn		
Resistance in Ohm	18.36 Ω	5.02 Ω

3.4.2 Feedback panel

Testing Table 19. Sample #2.6, has proven that the LEDs and vibration motors can work together in series on a knitted textile panel the same way as in Figure 7. LED and vibration motor on breadboard in series with 12 LEDs and 2 vibration motors.

However the structure of this sample does not have the same structure as Figure 6. Series structure, Brainstorm conclusion. This is because there were only 2 proto type PCB with vibration motors available for testing. Now that they prove to be working, smaller PCB with vibration motors can be ordered to manufactured with all the components on it mentioned in Figure 7. LED and vibration motor on breadboard in series.

In Table 18. Sample #2.5 there is room for 6 of those small PCBs with vibration motors along with 12 LEDs in the middle of the design. This does have the same design as Figure 6. Series structure, Brainstorm conclusion.

Section 4 Prototype

This prototype is product as a conclusion of the research of this thesis, but will not be the final WBT prototype. The main focus of this prototype are the breathing sensors and the feedback panel. The 2 final samples (Table 13 and Table 19) from section 3 are used in this section. The 2.3.1 Product rules and regulations that where set aside in section 3 are taken into account in the prototype production as well, namely; Front closure should be a plastic zipper, shoulder straps should be adjustable (Figure 3. Adjustable strap).

The choice of material from both samples and thus the prototype is a white ground fabric of nylon, Single jersey, knitted in the circular knitting machine and a silver coloured, Shieldex silver plated polyamide, 3x3PurpleMiss, knitted on the circular knitting machine.

Table 13. Parameters Sample #7will be used as the base for the product, the main body of the vest. Below this a feedback panel layer will be added. Table 19. Sample #2.6 will be used for this. The construction of the proto type was a rather simple process. Because circular knitting was used, cutting lines where included in the sample design. This way no patterns where needed to produce the proto type. The raw edges of the proto type where finished with Figure 16. Double folded bias tape. The yarn with which this is done is made from polyester.

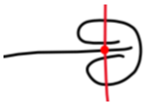


Figure 16. Double folded bias tape

A technical drawing was made (Figure 17. Technical drawing updated WBT prototype). This drawing can be compared to Figure 18. Technical drawing existing WBT prototype. The main body of the vest stayed the same, only the updated proto type has less seams because there is no need for the separate elastic breathing sensors. Also the battery part is not visible in the updated proto type because that is outside of the scope of this research and will be implemented later on in the project. Pictures of the final prototype can be found in Table 22. Prototype pictures.

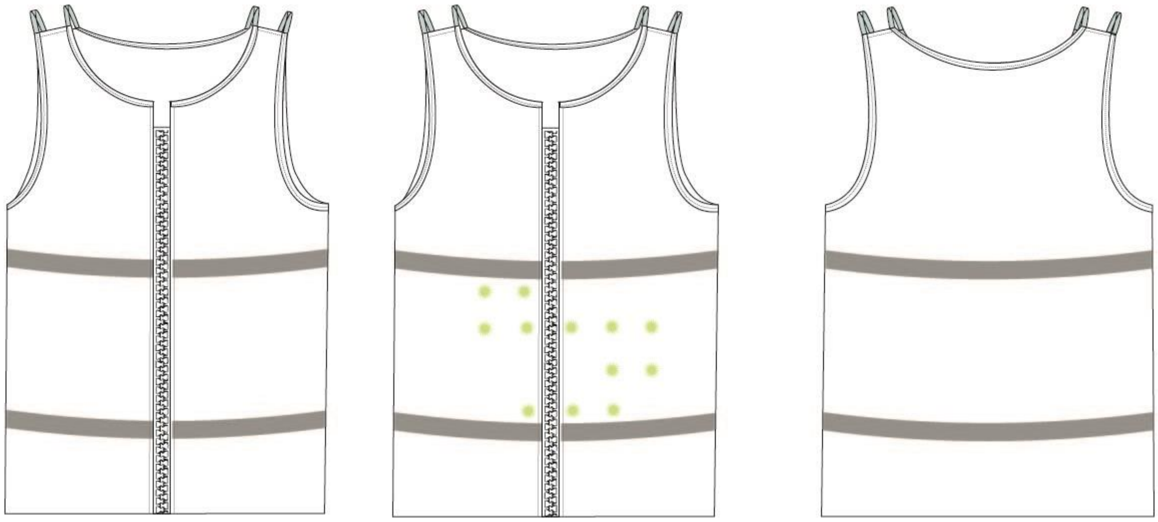


Figure 17. Technical drawing updated WBT prototype

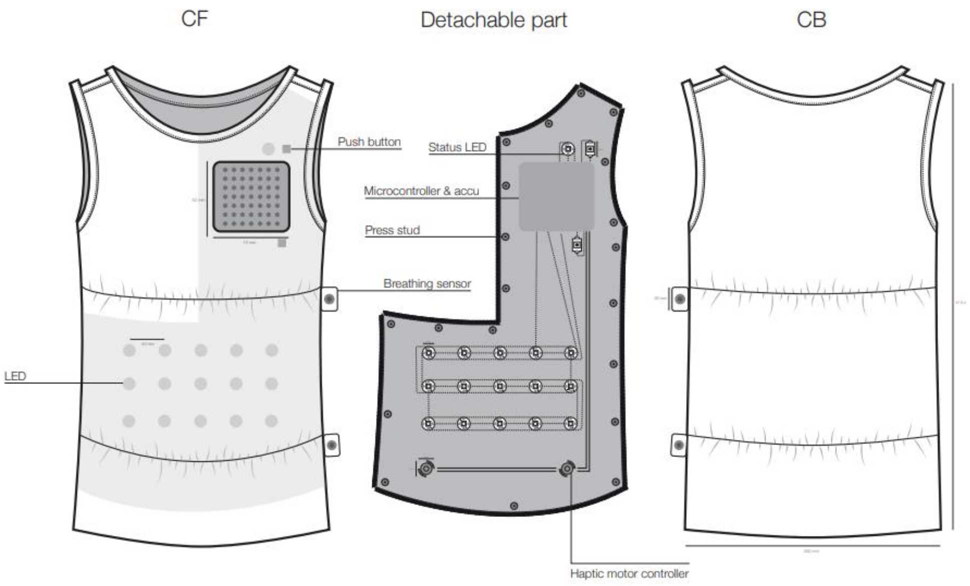


Figure 18. Technical drawing existing WBT prototype

Table 22. Prototype pictures

Front on model	Back on model	Front flat
		

Back flat	Inside
	

Section 5 Evaluation and implementation

5.1 Final evaluation

The final prototype of this research couldn't be evaluated by the end-users. It is not allowed to test smart textile products on children without an approved METC request. Project partner MST needs to request an METC for performing the user tests. This METC takes a lot of time to construct and thus it will only happen one time for the 4 year WBT project. In the 6th half year of the project the user tests will start. 4 months before this starts, the METC request needs to be submitted.

What can be done for the final evaluation of this research is evaluating the design criteria as shown in Table 3. Design criteria. To make a clear overview Table 23. Design criteria evaluation was created.

Table 23. Design criteria evaluation

	Design criteria	Method for validity	Evaluation
1.	The prototype should be a smart textile wearable that is safe for children.	Expert interview.	All the advice and rules that were applicable for this research Geelhoed (2022) were applied in the final prototype. More specifically; the closure (namely plastic zipper) and strap adjusters were used in the final prototype.
2.	Children should be able to take on and off the garment by themselves.	End user test. Literature.	The closure of the main layer is moved to the middle of the vest. This makes it possible for children to take on and off the garment by themselves (Siering, 2018). This will be evaluated and confirmed by the end user after the METC request. The haptic feedback layer is not adapted to this middle closure yet.
3.	The inside of the garment should feel soft on the skin like textile. This should be achieved by integrating the sensors and the feedback panel in the textile instead of on top of the textile.	End user test.	The inside of the prototype in the front is the inside of the feedback panel. This used to be stitched on data, ground and power lines. This is now knitted directly into the textile instead. Apart from the hand stitched attachment of the LEDs and PCBs the front inside feels soft like textile. The inside of the prototype in the back is the main layer with the breathing sensors. This used to be a tunnel with an elastic with a copper wire. This is now knitted directly into the textile instead. The back inside feels soft like textile. All of this will be evaluated and confirmed by the end user after the METC request
4.	The prototype should be more robust than the existing prototype.	End user test.	This will be evaluated and confirmed by the end user after the METC request.

5.	The breathing sensors should be reduced in bulk by integrating the sensors in the textile instead of on top of the textile	Expert meeting with Ben Bulsink. Literature.	With the expertise of Ben Bulsink and literature (Santoni Circular knitting machine, SM8-EVO4J) the breathing sensors are developed. These sensors are knitted into the main body of the vest. This eliminates a tunnel with an elastic with a copper wire, and thus reduces the bulk of the breathing sensors.
6.	The breathing sensors should be produced with industrial scale production methods.	Expert meeting with Ben Bulsink. Literature.	With the expertise of Ben Bulsink and literature (Santoni Circular knitting machine, SM8-EVO4J) the breathing sensors are developed. They are produced by means of circular knitting which is appropriate for industrial scale production (Semnani, 2011).
7.	Production steps of the breathing sensors should be reduced.	Expert meeting with Ben Bulsink. Literature.	With the expertise of Ben Bulsink and literature (Santoni Circular knitting machine, SM8-EVO4J) the breathing sensors are developed. The production steps used to be; fabric production, elastic band production. Putting the copper wire in the elastic, sewing a tunnel in the fabric and putting the elastic band in the tunnel. Because the sensors are now knitted directly into the fabric, there is no other production step fabric production. And thus steps are reduced.
8.	The haptic feedback panel should be reduced in bulk, by integrating the connection lines in the textile instead of on top of the textile and minimising the connection lines.	Brainstorm session. Expert meeting with Harry Sanderink. Literature.	With the expertise of Harry Sanderink, a brainstorm session and literature (Santoni Circular knitting machine, SM8-EVO4J) the haptic feedback panel is developed. The data, ground and power line are knitted directly into the fabric. This eliminates those lines being stitched through the fabric, and thus reduces bulk.
9.	The haptic feedback panel should be produced with industrial scale production methods.	Brainstorm session. Expert meeting with Harry Sanderink. Literature.	With the expertise of Harry Sanderink, a brainstorm session and literature (Santoni Circular knitting machine, SM8-EVO4J) the haptic feedback panel is developed. This is produced by means of circular knitting which is appropriate for industrial scale production (Semnani, 2011).
10	Production steps of the haptic feedback should be reduced.	Brainstorm session. Expert meeting with Harry Sanderink. Literature.	With the expertise of Harry Sanderink, a brainstorm session and literature (Santoni Circular knitting machine, SM8-EVO4J) the haptic feedback panel is developed. The production steps used to be; fabric production, stitching data, ground and power line and attachment of LEDs and motors. Because the data, ground and power line are now knitted directly into the fabric, the production steps are; fabric production and attachment of LEDs and motors. And thus steps are reduced.

Clarification Table 23. Design criteria evaluation;

1. Recommendations (5.2 Implementation) are made to ensure safety in further development based on Geelhoed (2022).

2. The haptic feedback layer is not adapted to this middle closure yet. This is because the haptic feedback research is only just beginning. For easier testing the layout of Figure 6. Series structure, Brainstorm conclusion is preferred. The important part of the sample conclusion is that the theory works, later on when the preferred layout for the final product is known (based on haptic feedback research). The layout can easily be adapted or split up in 2 different panels with the technology researched and explained in this research.

3. The handstitched attachment of the LEDs and PCBs are not the final attachment way. This was just used for easy prototyping. More research about this attachment method should be done, but this is outside of the scope of this research. recommendation on the attachment method can be found in 5.2 Implementation.

5.2 Implementation

Wearable Breathing Trainer

Because of this research the WBT project partners now have insight into the appropriate technology to use in the production of the garment as well as prototypes and samples of these solutions. This will enable the project to proceed to its next steps with a fundamental basis on functional & reliable textile integration.

As explained in 5.1 Final evaluation, the garment cannot be tested by the end user. To still get a (kind of) visual implementation on the end user, the final prototype has been photographed on children (Table 24).

Table 24. Final prototype implemented

Knowledge transfer

Throughout the research, knowledge was generated and transferred to studenta in the textile field. This knowledge contributes to the field and is based on practical know how. Figure 19 and Figure 20 are 2 pictures taken during Smart textile lessons given by the author to the second years (6 classes were taught in total) of the bachelor Fashion and Textile Technologies.

In these lessons the authors own made knitting bindings where explained. The finding with these bindings related to resistance is practical know how that cannot be found in books. This research was the only reason and possibility that this knowledge could be transferred to the new generation. The lessons were in a workshop style with hands-on assignments. With the Multimeter, the student really got to experience the resistance difference in the different structures. Multimeter results are not as accurate as Figure 9. Systematic 4 point measuring method setup, however it is accurate enough for educational purposes.

During the lessons, the students were checked on their answers and the author made sure that everybody had the correct answer and understood why, before moving on to the next assignment. In the 6 classes everybody ended up with the same answers, this makes the lessons reliable and valid. This proves the relevance for the textile field and for professional practice. Since the next generation textile experts were educated with the findings of this research.

Figure 19. Smart textile lesson; knitting structures for improved resistance

Figure 20. Smart textile lesson; students and author

Future Research

The prototype created for this research is not the final design, for the person that will continue the design process these recommendations are formulated.

Safety is the biggest concern for smart textiles, especially the fear of electric shocks (Shuvo, Decaens, Lachapelle, & Dolez, 2021). In the interview conducted with an expert from Modint, a NEN draft report was discussed. This is an ISO norm called: con In this report the values of maximum amount power that is allowed to flow in a textile fabric is made public. All the participating country's vote for the norm on the 17 of May 2022, and if the voting is won the publish date will be around the end of 2022. Recommended is that this report and its mentioned values are taken into account when further developing the WBT prototype. This is important because the prototype needs to abide by the relevant rules and regulations.

In general it is recommended for the next person to continue the design process of the WBT, to read through the interview transcript before they begin designing and researching. This way easy avoidable mistakes are eliminated. If more questions arise after reading the transcript, Geelhoed (2022) mentioned that she is open to answer all the questions and look into future design sketches.

Techtextil in Frankfurt will be happening on 23 of June 2022. In this event a lot of different conductive yarn types will be displayed and explained. This event is too late to be implemented in the report but the author will go there and report some information on different kinds of conductive yarn. Recommended is that this info is taken into account when the design process continues. With this info it is a wise decision to test with the yarn that is hypostasised to function the best for this product. When these prove to lower the resistance, the structure Figure 21. 2x2PurpleMiss.Pat can be put on the conductive material and the amount of rows can be reduced. This will save on conductive yarn and thus in costs.

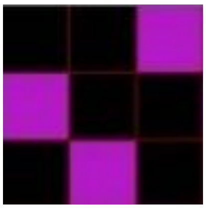


Figure 21. 2x2PurpleMiss.Pat

In Table 19. Sample #2.6 some connections were not so stable. Ben Bulsink had a look at it and suspected it was the attachment method of the LEDs and PCBs. However, research needs to be done if it is in fact this or if the problem lies somewhere else.

On 08-06-2022 the Table 20. PCB with vibration motor were developed by another student working on the WBT. Because of time issues this part has not been more researched by the author and has for some part moved to the recommendations.

If it is the attachment with hand stitched conductive yarn, different options need to be researched. Glueing with conductive glue is hypothetically a good way and should have some focus within the research. If the problem is not the connections but the fabric and its stretch, laminating is a good technology to look into. Laminating can also be used for creating a barrier in between the 2 layers of the WBT to prevent short circuit or mixed signals.

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Section 6 Process reflection

The design process of this research was based on Figure 1. Design Thinking Model. The model was very useful for the research because section 2 and 3 were happening simultaneously; Gathering info in section 2 testing and design within section 3 and finding out new information through this for section 2. For example, some samples were designed before the expert meetings and the development of the breathing sensors (part of conclusion section 3) was done before the expert meeting about the feedback panel. At first the author had some problem structuring the report, however the development flowed really natural. When more info and design samples were made it was easy to make a good structure. Namely all the information for the design process in section 2 and all the design steps and sample production in section 3.

In section 1 the problem definition and the design criteria on which this study was based are explained. The information for this was taken from the project plan of the WBT project, (Ludden, Mader, van Rees, & Siering, 2019), this is an up to date and relevant report for my thesis and this ensures that the problem definition is in line with what the company expects.

In section 2 all the missing information is gathered to start the design process. This happened by means of literature, expert interview, expert meeting, testing, desk research and brainstorm session. Within the literature I used. Later on I found that the info used in my literature was a bit superphysical for certain topics. I really needed the experts for in-dept information. For example, with circular knitting, my literature is accurate and valid, but that still didn’t give me enough expertise to start my design process with knitting.

For safety rules of a smart textile garment for children, no credible sources were found and thus an expert was needed as well. Modint is thé branch organisation of the Dutch textile world. A child safety expert from Modint answered all questions about child safety in combination with smart textiles. This is a very credible and reliable expert interview, however there aren’t a lot of rules for smart textile because it is such a new topic. But all the rules that are valid in the EU/the Netherlands are known at Modint.

To make sure my knitted breathing sensors would work with the Breathpal sensor an interview with Ben Bulsink was conducted. The interview gathered reliable information from the person that made the Breathpal sensor. This way the author was sure that the information mentioned was accurate. In this meeting it became clear

Harry Sanderink teaches the principles of electronics in smart textiles at the master of Saxion. This means that he has a lot of knowledge on electronics, sensors and actuators. For the parameters of the feedback panel he was a relevant expert.

The resistance testing used in this research is according to the (NEN-EN 16812 - Textiles and textile products - Electrically conductive textiles - Determination of the linear electrical resistance of conductive tracks , 2016). This is the most reliable norm organisation for these tests within the Netherlands.

Section 7 Personal reflection

When I started with this research I had never used an automatic knitting machine. I really enjoyed learning a new skill, namely knitting with the santonin circular knitting machine. It was quite a challenge but I enjoyed the process.

In march, the kick-off of the WBT project was held at Saxion. This was an event with all the stakeholders from different companies. It was a really cool experience for me because it was a look into the 'real' textile world. With professional outside of Saxion. I was already quite far with the development of the breathing sensors at this point. A lot of stakeholders were interested in my knitting experiment with different structures to lower the resistance. Multiple people actually told me I should write an actual research report about it. I was quite flattered.

I worked independently throughout my research but I felt very comfortable asking questions about stuff I didn't know. I didn't have experience with smart textile and thus I had a lot of questions. But the nice thing about the research group is that is always someone to ask these questions to. Also a lot of project partners were very helpful. I especially learned a lot from Ben Bulsink who basically had to explain me the basic about electrical resistance. And from there on my development begun.

Overall I experienced writing this thesis as a positive, and educational process but there are some improvements possible on my side.

For example I always start with the fun stuff. If I have to read literature (which is pretty boring and hard for me to with my dyslexia sometimes) or use the knitting machine to make some samples, I will always start with the knitting part first. Because I enjoy this more. However this leaded into doing somethings in a not so logical order sometimes. And when I knitted the samples I didn't put in the report the info right away, which is a very tedious task to do at the end for all the samples.

So I would like to improve my attitude toward *fun and boring* tasks, and just do what needs be done when it needs to be done.

Afterword from the company

Dear reader,

Sanne has been involved within the research group SFT in the Wearable Breathing Trainer Project to develop several technology integrations in textiles. She's directly started very progressively and hands on by knitting samples on the Santoni circular knitting machine and getting to know the design software, etc. This enabled us to already show some very interesting results during the project kick-off. Besides that, she immediately proved to be a great team member in the project and the research group, often thinking along and helping others on parts that may be beyond the scope of her own research. This proved to be a great asset in the project by, for example actively taking part in one of the brainstorms during the project kick-off and recent focus group and by own initiative preparing relevant questions, taking relevant notes, for the other work package leader, who also thought this to be very helpful. The writing of the research is, because of all the activities, still a work in progress, but I have no doubt the final report will also meet the required standards. With this I see that Sanne has the talent to work in complex multi/transdisciplinary projects and has a natural curiosity to explore, be part of teams, but also work independently, while not being afraid to approach others and ask questions.

Best regards,

Hellen van Rees MA.

Researcher Sustainable & Functional Textiles.

Enschede,

26-05-2022

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Appendices

Appendix 1. Interview transcript Modint

The interview was conducted in the mother tong of the expert and the interviewer, namely Dutch. The expert send an email with all the pictures and sites discussed during the interview. To make reading the transcript more clear I added these links and pictures when they were mentioned.

Interviewer: Dit interview gaat over het Wearable breather trainer project, waar jullie project partner van zijn. De wearable breather trainer bestaat uit 2 onderdelen. De basis van het vestje, waar 2 sensoren in zitten. 1 rond de buik en 1 rond de borst. Elastieken band met koper. Deze staan in contact met het 2de onderdeel; het feedback paneel. Hier in zitten lichtjes en vibratie motoren die werken aan de hand van de sensoren. Ook zit er een printplaatje en een batterij op het vestje die vast zit aan beide lagen.

In mijn onderzoek ben ik de sensoren en het feedback paneel aan het breien met geleidend garen en zo zijn heel veel kabeltjes en losse elementen niet meer nodig. Mijn vragen in dit interview gaan over de elektronische componenten en de verbinding hier tussen. En over standaard regelgeving voor de doelgroep. Hier is ook een foto van het prototype.

Het Product is voor 6 tot 12 jaar oud. Zijn de regels voor die groep grotendeels hetzelfde of is daar veel verschil tussen? Is er bijvoorbeeld voordeel om deze leeftijd categorie iets aan te passen?

Expert: de regels verschillen sowieso voor 0 tot 3 dit gaat met name over kleine onderdelen. Het wordt verkocht als medical device neem ik aan. Young child is van 0 tot 7. Dat is tot en met 6 jaar en 11 maanden. En dan is inclusief alle kinderen met een hoogte van 134 cm. komt overeen met Nederlandse kindermaten. 0 tot 6 jaar en 11 maand heeft andere regelgeving dan 7 tot 12, dus dat is dan een logischere doelgroep. De leeftijd groepering die over child savety gaat, gaat meer over wat een kind kan en hoe een kind zich gedraagt. Bij jullie product gaat het er ook om dat het een bepaalde pasvorm heft. Dus je zou naar maat tabellen moeten kijken voor kinderen om te beslissen hoeveel maten je gaat aanbieden. Goed naar die lichaam lengte kijken die erg relevant is. Wij hebben van Modint uit maat tabellen, voor Nederlandse kinderen, die zijn een stukje langer, dat verschilt per land. Dus ik stuur jou de maat tabellen door. En hou hierbij rekening met de groei curve.

https://www.tno.nl/nl/aandachtsgebieden/gezond-leven/roadmaps/youth/groeidiagrammen-in-pdf-formaat/

BoYs

	Sizing Table						Averages							
	Boys	A	A	A	B	B	B	B	B	B	B	B	B	B
	Size	**50**	**56**	**62**	**68**	**74**	**80**	**86**	**92**	**98**	**104**	**110**	**116**	**122**
	Age (median)	0,1	0,1	0,3	0,5	0,9	1,2	1,8	2,3	3,1	3,8	4,5	5,5	6,5
	Weight (median)	3,8	5,0	6,2	8,1	9,4	11,0	12,3	13,7	15,3	16,7	18,9	20,7	23,3
1	stature	50,0	56,0	62,0	68,0	74,0	80,0	86,0	92,0	98,0	104,0	110,0	116,0	122,0
2	chest circ	36,6	39,4	42,2	44,5	46,2	48,0	49,8	51,6	53,3	55,1	56,9	58,7	60,4
3	waist circ	32,9	36,2	39,5	41,9	43,4	44,9	46,4	47,9	49,4	51,0	52,5	54,0	55,5
4	hip circ	30,7	34,4	38,2	41,2	43,6	45,9	48,2	50,6	52,9	55,2	57,6	59,9	62,2
5	head circ	35,8	38,6	41,4	44,0	46,2	47,8	48,9	49,8	50,5	51,0	51,3	51,6	51,9
6	neck circ	20,9	21,5	22,2	22,8	23,5	24,1	24,8	25,4	26,1	26,7	27,4	28,0	28,7
7	upper arm circ	11,3	12,8	14,2	15,2	15,6	16,0	16,4	16,9	17,3	17,7	18,1	18,5	19,0
8	upper leg circ	18,5	21,5	24,4	25,5	26,7	27,9	29,2	30,4	31,6	32,9	34,1	35,3	36,6
9	back length	16,2	17,6	19,0	20,1	20,9	21,7	22,6	23,4	24,2	25,1	25,9	26,7	27,5
10	back width	12,5	14,5	16,4	17,9	19,1	20,3	21,4	22,6	23,8	24,9	26,1	27,2	28,4
11	arm length	16,1	18,2	20,3	22,5	24,7	27,0	29,2	31,5	33,7	35,9	38,2	40,4	42,7
12	upper arm length	8,3	9,6	10,9	12,3	13,6	14,9	16,3	17,6	18,9	20,3	21,6	22,9	24,3

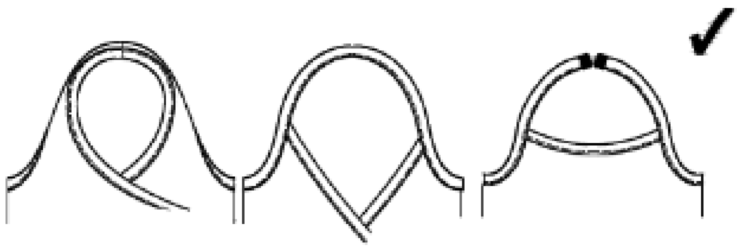
		© 2014 TNO, SizingScience													Step Size			SD		
	Boys	B	B	C	C	C		C	C	C	C	C	C	C	A	B	C	A	B	C
	Size	**128**	**134**	**140**	**146**	**152**		**158**	**164**	**170**	**176**	**182**	**188**	**194**	**50-62**	**68-134**	**140-194**	**50-62**	**68-134**	**140-194**
	Age (median)	7,5	8,6	9,7	10,6	11,4		12,2	13,4	14,9	16,9	17,8	18,8	19,1						
	Weight (median)	25,7	29,4	32,7	36,0	40,8		44,5	50,6	58,0	64,6	70,3	76,0	80,3						
1	stature	128,0	134,0	140,0	146,0	152,0		158,0	164,0	170,0	176,0	182,0	188,0	194,0	6,00	6,00	6,00			
2	chest circ	62,2	64,0	66,5	69,7	73,0		76,2	79,5	82,7	86,0	89,2	92,5	95,7	2,81	1,77	3,25	3,34	2,90	5,66
3	waist circ	57,0	58,5	60,6	63,2	65,7		68,3	70,9	73,4	76,0	78,6	81,2	83,7	3,29	1,51	2,57	2,47	3,34	7,74
4	hip circ	64,6	66,9	69,7	73,1	76,4		79,7	83,1	86,4	89,7	93,1	96,4	99,7	3,74	2,34	3,33	3,01	3,79	7,16
5	head circ	52,2	52,5	53,0	53,4	53,9		54,5	55,0	55,7	56,3	56,9	57,5	58,2				1,26	1,56	1,59
6	neck circ	29,3	30,0	31,1	32,7	34,2		35,8	37,4	39,0	40,6	42,1	43,7	45,3	0,64	0,65	1,58	1,70	1,53	2,48
7	upper arm circ	19,4	19,8	20,5	21,5	22,5		23,6	24,6	25,6	26,6	27,6	28,6	29,6	1,45	0,42	1,01	1,23	1,36	2,88
8	upper leg circ	37,8	39,0	40,6	42,5	44,4		46,2	48,1	50,0	51,3	53,8	55,7	57,6	3,11	1,08	1,65	1,20	2,37	3,89
9	back length	28,4	29,2	30,5	32,3	34,1		35,9	37,7	39,5	41,3	43,1	44,9	46,7	1,38	0,83	1,80		1,69	2,58
10	back width	29,6	30,7	32,0	33,3	34,7		36,0	37,4	38,7	40,1	41,4	42,8	44,1	1,93	1,16	1,35	1,07	1,72	2,95
11	arm length	44,9	47,2	49,5	52,0	54,4		56,9	59,4	61,8	64,3	66,8	69,2	71,7	2,08	2,24	2,46	1,11	1,52	2,17
12	upper arm length	25,6	26,9	28,3	29,7	31,1		32,6	34,0	35,4	36,8	38,2	39,7	41,1	1,33	1,33	1,42		1,36	1,73

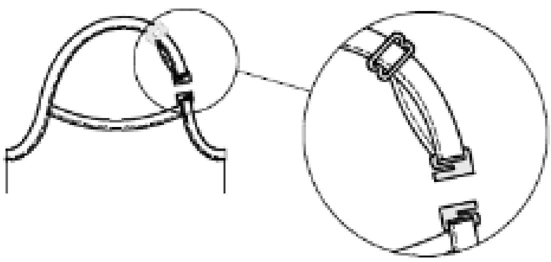
	GIRLS																														
Sizing Table							Averages							© 2014 TNO, SizingScience												Step Size			SD		
	Girls	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	A	B	C	A	B	C
	Size	**50**	**56**	**62**	**68**	**74**	**80**	**86**	**92**	**98**	**104**	**110**	**116**	**122**	**128**	**134**	**140**	**146**	**152**	**158**	**164**	**170**	**176**	**182**	**188**	**50-62**	**68-134**	**140-194**	**50-62**	**68-134**	**140-194**
	Age (median)	0,1	0,2	0,3	0,6	0,9	1,5	1,9	2,4	3,1	3,9	4,7	5,6	6,7	7,5	8,7	9,8	10,5	11,6	13,1	15,4	16,3	17,7	18,0	20,1						
	Weight (median)	3,8	4,8	6,2	7,8	9,2	10,5	11,8	13,3	15,2	16,8	19,1	21,0	23,5	26,1	29,1	33,3	36,4	41,5	49,4	55,4	59,6	65,7	70,8	74,2						
1	stature	50,0	56,0	62,0	68,0	74,0	80,0	86,0	92,0	98,0	104,0	110,0	116,0	122,0	128,0	134,0	140,0	146,0	152,0	158,0	164,0	170,0	176,0	182,0	188,0	6,00	6,00	6,00			
2	chest circ	36,5	39,4	42,2	44,5	46,2	48,0	49,7	51,4	53,2	54,9	56,7	58,4	60,1	61,9	63,6	67,0	71,9	76,8	81,8	86,7	91,6	96,5	101,5	106,4	4,36	1,59	4,95	2,07	2,96	6,02
3	waist circ	33,6	36,5	39,3	41,5	43,1	44,6	46,2	47,8	49,3	50,9	52,5	54,0	55,6	57,2	58,7	60,7	63,0	65,3	67,7	70,0	72,3	74,6	76,9	79,3	2,84	1,57	2,32	2,41	3,56	7,44
4	hip circ	31,1	34,7	38,4	41,4	43,8	46,2	48,6	51,0	53,5	55,9	58,3	60,7	63,1	65,5	68,0	71,2	75,4	79,6	83,7	87,9	92,0	96,2	100,4	104,5	3,63	2,42	4,16	2,95	3,96	7,73
5	head circ	35,3	38,2	40,9	43,4	45,4	46,8	47,9	48,8	49,5	50,0	50,3	50,6	51,0	51,4	51,9	52,4	53,0	53,5	54,1	54,7	55,2	55,8	56,4	57,0				1,30	1,46	1,55
6	neck circ	21,0	21,5	21,9	22,5	23,3	24,0	24,8	25,6	26,4	27,1	27,9	28,7	29,5	30,2	31,0	32,1	33,6	35,0	36,4	37,9	39,3	40,8	42,2	43,6	1,08	0,78	1,19	1,44	1,40	1,75
7	upper arm circ	11,4	12,7	14,0	14,9	15,4	15,9	16,4	16,9	17,5	18,0	18,5	19,0	19,5	20,1	20,6	21,3	22,3	23,2	24,2	25,1	26,1	27,0	28,0	28,9	1,28	0,52	0,95	1,26	1,40	2,64
8	upper leg circ	18,8	21,1	23,4	25,3	26,9	28,5	30,1	31,7	33,3	35,0	36,6	38,2	39,9	41,5	43,1	45,5	48,5	51,6	54,6	57,7	60,8	63,8	66,9	70,0	2,70	1,44	2,80	1,20	2,50	4,28
9	back length	16,3	17,6	18,8	19,9	20,8	21,7	22,6	23,5	24,4	25,3	26,2	27,1	28,0	28,9	29,8	31,2	33,2	35,1	37,1	39,0	41,0	42,9	44,8	46,8	1,27	0,90	1,94		1,62	2,06
10	back width	12,3	14,7	17,1	18,6	19,3	20,0	20,7	21,4	22,1	22,8	23,5	24,2	24,9	25,6	26,3	27,3	28,8	30,3	31,8	33,2	34,7	36,2	37,7	39,1	2,41	0,69	1,47	1,07	1,71	2,13
11	arm length	16,1	18,3	20,5	22,6	24,8	26,9	29,0	31,1	33,2	35,4	37,5	39,6	41,7	43,9	46,0	48,2	50,5	52,8	55,2	57,5	59,8	62,1	64,4	66,8	2,19	2,12	2,32	1,11	1,54	1,93
12	upper arm length	9,0	10,2	11,4	12,6	13,7	14,9	16,1	17,3	18,4	19,6	20,8	22,0	23,1	24,3	25,5	26,7	28,0	29,2	30,5	31,8	33,0	34,3	35,6	36,8	1,18	1,18	1,27		1,01	1,32

Als het product trouwens alleen onder toezicht gebruikt wordt vraag ik me af of je aan de regels hoeft te houden. Maar als kinderen dit ook zonder toezicht moeten dragen moet je je wel aan deze standard regels houden.

Interviewer: In de hoofd/hals zone, op de schouders kan je de hoogte/maat van het product aanpassen. Dat gebeurd nu met strikjes. Wat zijn de regels hierover? Moet het bijvoorbeeld met klittenband/knopen? Wat is uw advies?

Expert: dan zou ik kiezen voor zoiets, ik mail je het Plaatje ook toe. Dit is lingerie smalle breedte maar ik zou voor lingerie brede breedte gaan. En misschien hoeft er helemaal geen klip opening mee.





Ik train zelf met bepaalde pakken waar sensoren op zitten. Daar hebben ze klittenband van boven die ze over de schouder heentrekken. Daarmee zet je hem strak. Dat is misschien ook wel een goede optie. Deze foto zet ik ook in de mail. Je doet hem eerst met een rits dicht en dan trek je aan de zijkant strak. Klittenband mag gewoon zolang het niet met de prikkel kant op de huid komt.

Interviewer: In dit project zijn we bezing alle elektronische componenten die nodig zijn voor de werking beter te integreren in het product. De printplaat en batterij worden nu verstopt in een 3d geprint lego doosje. Bijna alle draadjes die hier naartoe lopen worden vervangen met geleidend garen wat in de stof gebreid is. De losse kabeltjes zullen alleen nog in het lego doosje voorkomen. Is dit robuust genoeg? Ziet u hier problemen? Wat is uw advies?

Expert: sowieso mag losse lege niet, dus als je zoon doosje hebt met een lego print dan is dat prima, maar de lego die een kind er op maakt is dan van het kind en volg lego regels dus dat maakt dan voor jullie niet uit. Je moet er voor zorgen dat in het doosje de elektrische component niet toegankelijk zijn met een schroevendraaiertje. Zo kunnen wel de ouders en de fysio's erbij. Dat komt uit de speelgoed norm. batterij mag niet zomaar toegankelijk zijn. Voor de batterij stuur ik jou regelgeving op voor rugzakken met lampjes. Dat moet dan CE gemarkeerd worden

Interviewer: 4.De ademhaal sensoren zitten vast met metalen druk knoopjes. Zijn zulke knoopjes toegestaan? Wat zijn de regels over het bevestigen van zulke knoopjes?

Expert: nee daar zijn alleen voor hele klein kinderen regels voor, zulke knoopje zijn gewoon goed.

Interviewer: De sensor zit met kabeltjes naar de print plaat. Wat zijn hier de regels voor?
Misschien in een textiele tunnel te verwerken dat dezelfde regels en lengtes als koordjes gelden?

Expert: ik zou de kabeltjes in een textiele tunnel verwerken. Het gevaar van kabels is dat kinderen er aan kunnen blijven hangen dus als je deze tunnel vast maakt aan de binnenkant van het product, zodat ze er niet aan kunne blijven hangen. Dan is het goed verwerkt. Dat ze het ook niet zelf uit kunne trekken. Mocht je later tekeningen en ideeën hebben stuur ze me dan even toe dan kijk ik erna.

Interviewer: er moet ook een aan en uit knopje aan het product komen. Zijn hier bepaalde regels voor?

Expert: nee als het maar goed vast zit.

Interviewer: De sluiting van het vestje wordt naar midden voor verplaatst. Wat voor een sluitingen zijn toegestaan voor deze leeftijd? Het liefst iets wat een beetje verstel baar is qua maat, wat raad je aan?

Expert: ik zou gewoon een plastic rits aan de voorkant maken.

Interviewer: Hebben jullie algemene regels over smart textiles? Wat is je advies hierover?

Expert: er zijn geen algemene regels over smart textiles. Maar ik heb wel Restriction of Hazardoud Substances, lood,kwik, cadmium, chroom en allerlij andere dingen wat er dus niet in mag zitten. Dan WEEE, Waste of Electrical and Electronical Equipment is een symbol wat er op moet. En Electromagnetic Compatibility en Battery Directive. Daar moet het in iedergeval aan voldoen. Als je dit googelt kan je het vinden op de website van de Europese unie. Je google 12 schrap 19 en dan kom je op de uitleg van dit.

Interviewer: welke materialen mogen de huid niet aanraken?

Expert: niet de scherpe kant van klittenband en metaal moet je ook mee uitkijken.

Interviewer: Hoeveel stroom mag er dan op het product staan?

Expert: Ik denk dat dat onder Electromagnetic Compatibility valt. Ik ga even kijken. Er zijn veel documenten die wel aangeven dat er regelgeving nodig is maar niet wat die regelgeving dan inhoud. Er is geen regelgeving of Europees maldaad. Dus ik denk dat er nog niet zoveel is..
Ik zie hier een draft van een ISO norm. Hier staat Electrical conductivity measured on a thin material arcoss oppisite ends of the area. Ik vraag me af of er dan veel vershil is tussen battery en of het aan het stroom hangt.
Dit document is relevant voor geleidende stoffen waaronder waaronder knitted. Jouwn product valt wel onder de scope van het verhaal. De test methode heet ISO/FDIS 24584: Textiles, Smart textiles, Test method for sheet resistance of conductive textiles using non-contact type. Op 17 mei wordt gestemd, dat betekend dat ie hopelijk eind van het jaar een geharmoniseerde standaard heeft en geaccepteerd door alle landen. Ik weet alleen nog niet welke stroom waarde hier dan aan vast zitten. Dus ik weet niet hoeveel je er voor nu aan hebt maar als dit uitkomt is het wel relevant voor jouw product. Verder hebben ze het hier in ook over de Ohms per oppervlakte, ik stuur je een screenshot van de inhoudsopgave mee.

Contents

Interviewer: zijn deze regels nog anders voor kinderen?

Expert: Nee de regels die er zijn, zijn gewoon algemeen en gelden voor allee leeftijden. In die ISO norm krijg je waarschijnlijk gewoon maximale waardes die kun je dan aanhouden.
Waar je naar nog zou kunnen kijken trouwens is andere producten waar stroom door loopt.
Ik stuur je een link van Honeywell, misschien interessant om dat door te lezen.
https://sps.honeywell.com/us/en/support/blog/safety/ppe-for-electrical-safety-antistatic-electrostatic-or-insulating

Interviewer: Er komen led lichtjes en vibratie motoren op het product. Heb je daar nog advies over?

Expert: in de speelgoed norm staat iets over damage to the eyes maar ik neem aan dat die ledjes niet zo vel zijn dat dat van toepassing is. Met de frequentie moet je wel rekening houden dat mensen met epilepsie er geen last van mogen hebben.

Interviewer: oké, ik heb het allemaal genoteerd. Dat waren wel mijn vragen. Heb je nog adviezen? of andere dingen die je aan het product zag, Waarvan je denk hier moet je op letten.

Expert: niks scherps, kijk goed uit voor randen van dingen enzo. en ik bedenk me nu, ik zag laatst iets. Somnox ik stuur de link. Kun je bij hun certification kijken. Dat is een kussen die moet helpen met ademhaling, misschien interessant.

https://somnox.com/

https://somnox.com/wp-content/uploads/2021/11/English-manual-somnox2.pdf

Ook is een goeie was instructie nodig als het product gewassen kan worden.

En het moet CE gecertificeerd worden waarschijnlijk onder het medical advice categorie. Maar dan moet je even weten wat een medical device is. Ik ben het even aan het opzoeken, ik stuur je de link door.

https://eur-lex.europa.eu/eli/reg/2017/745/oj

maar ook al claim je dat het geen medisch product is. Als het lijkt op een medisch product en dus bv door die fysio's gebruikt wordt denk ik van wel. Zoon Somnox koopt iemand zelf, en claimt niet voor een ziekte of aandoening te zijn. maar als je het van de fysio krijgt dan zou het wel onder medical device kunnen vallen.

Verder heb ik geen advies, ik stuur je een mail met alle info die ik beloofd heb en als je vragen hebt stuur me dan vooral een mailtje.

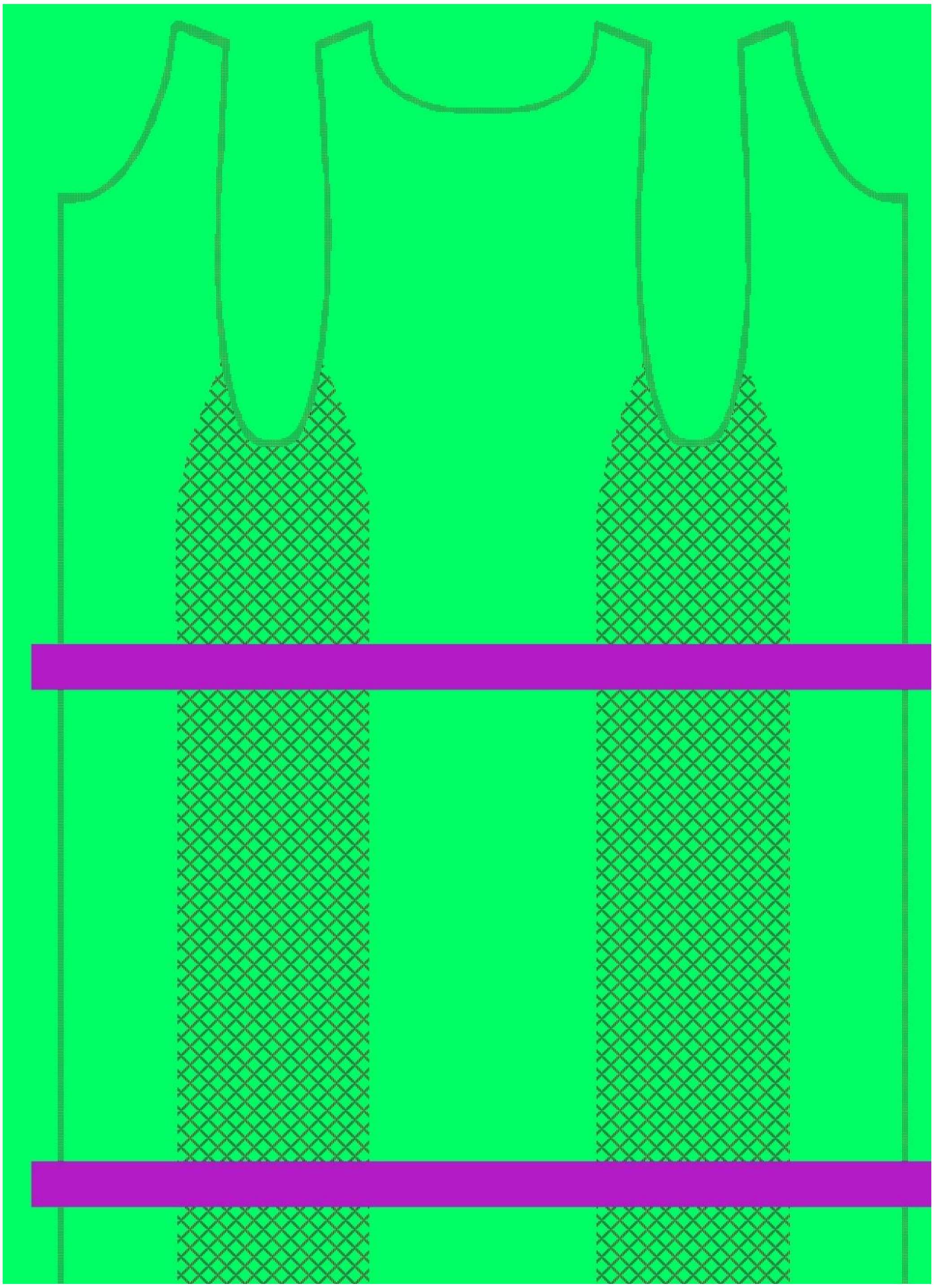
Interviewer: bedankt voor al je adviezen en je tijd en een fijne middag!

Appendix 2: .Dis drawings

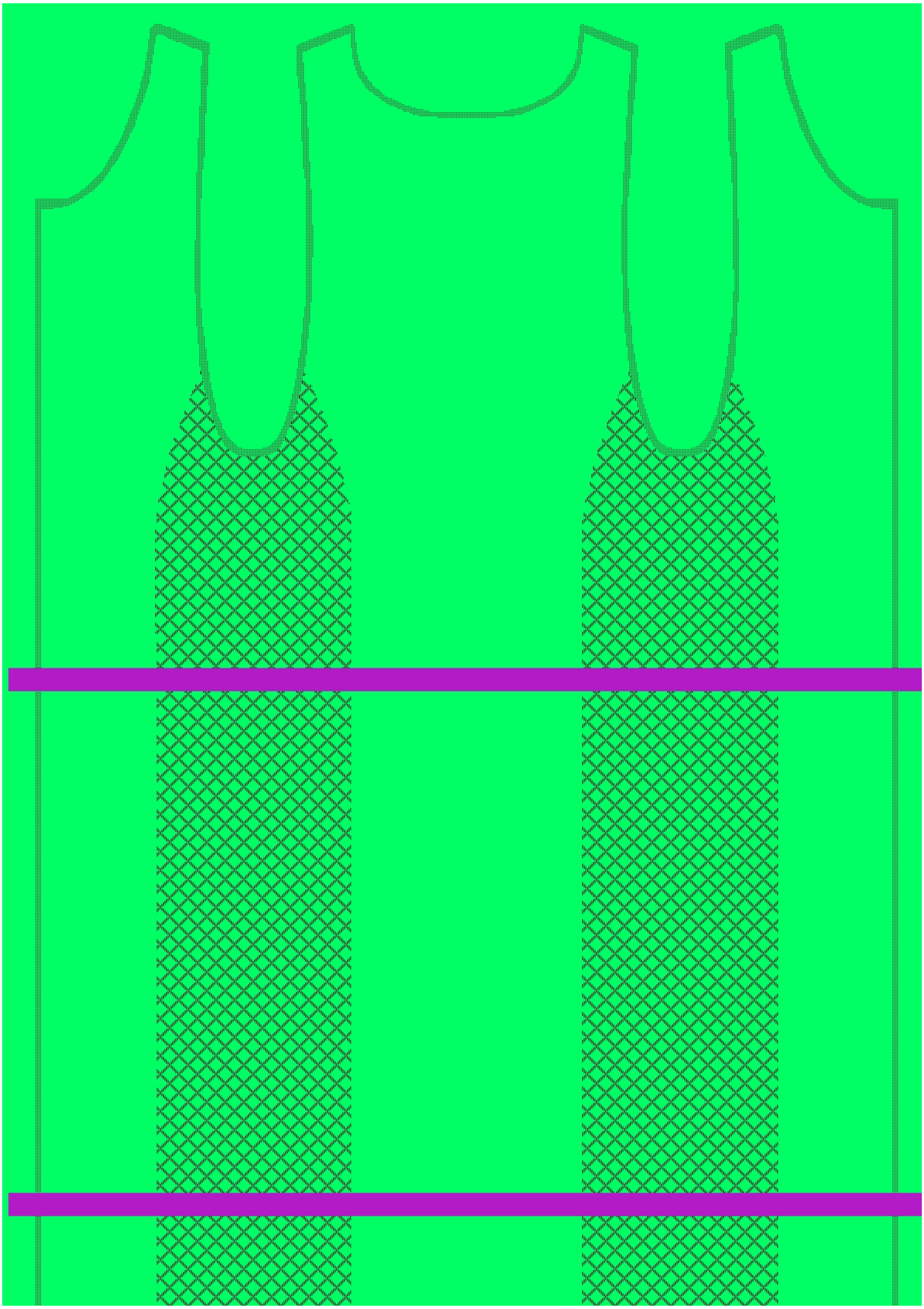
Here all the .Dis drawings of the research can be found. The meaning of the colours are mentioned in the table below.

2 colors	
	Plain
	Miss
	Float
	Color 1 (Conductive yarn)
	Color 2

Sample #1



Sample #2



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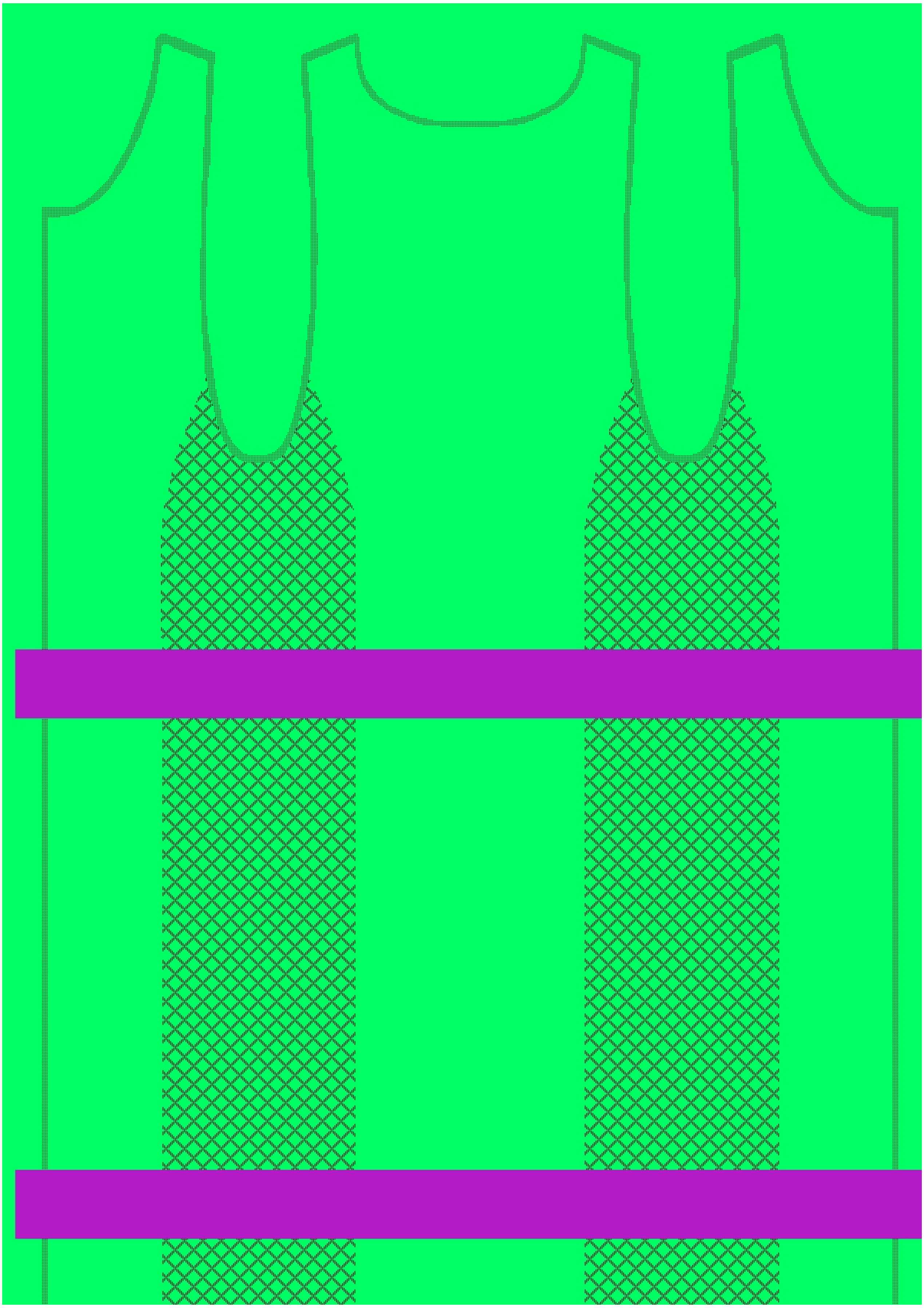
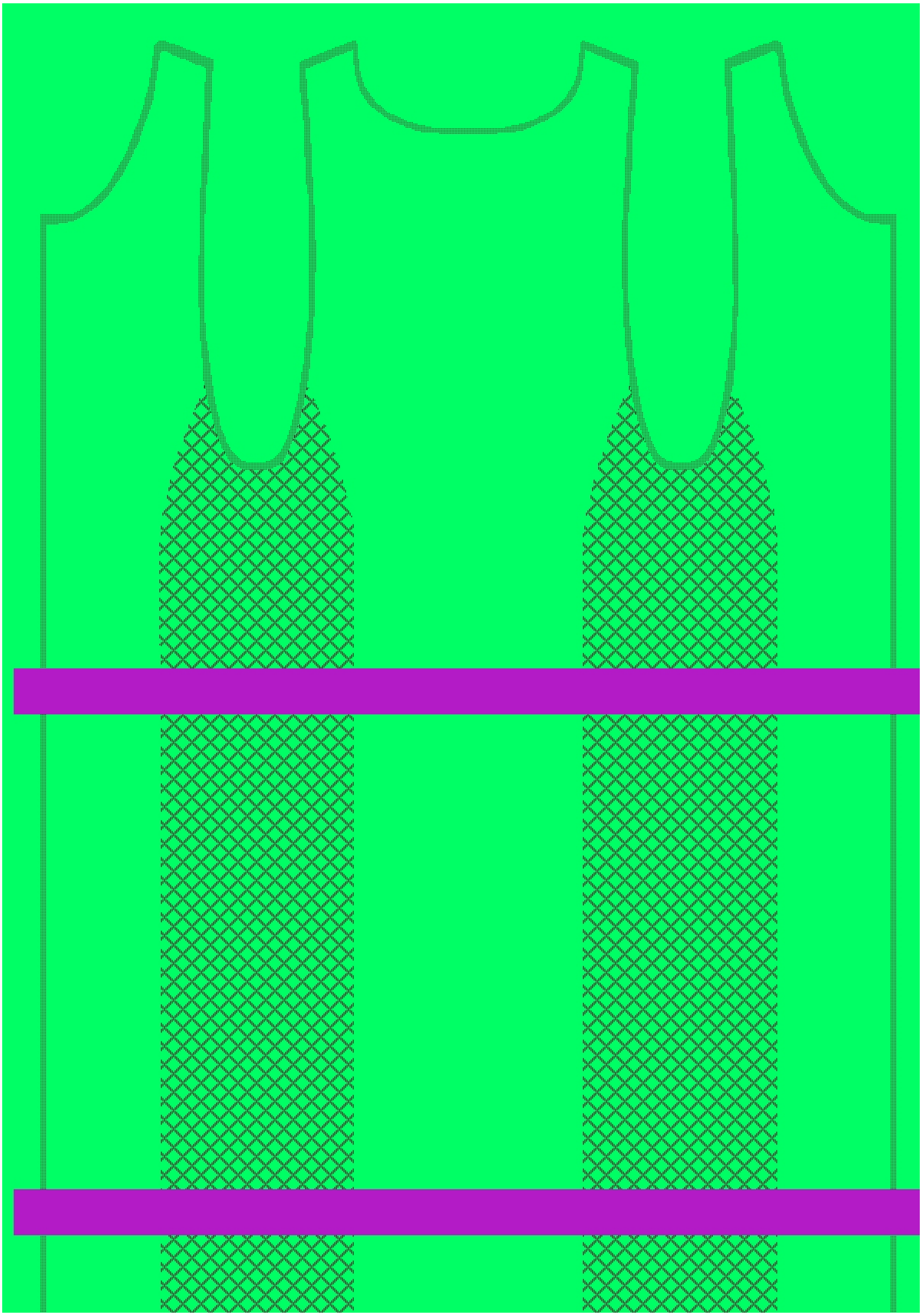


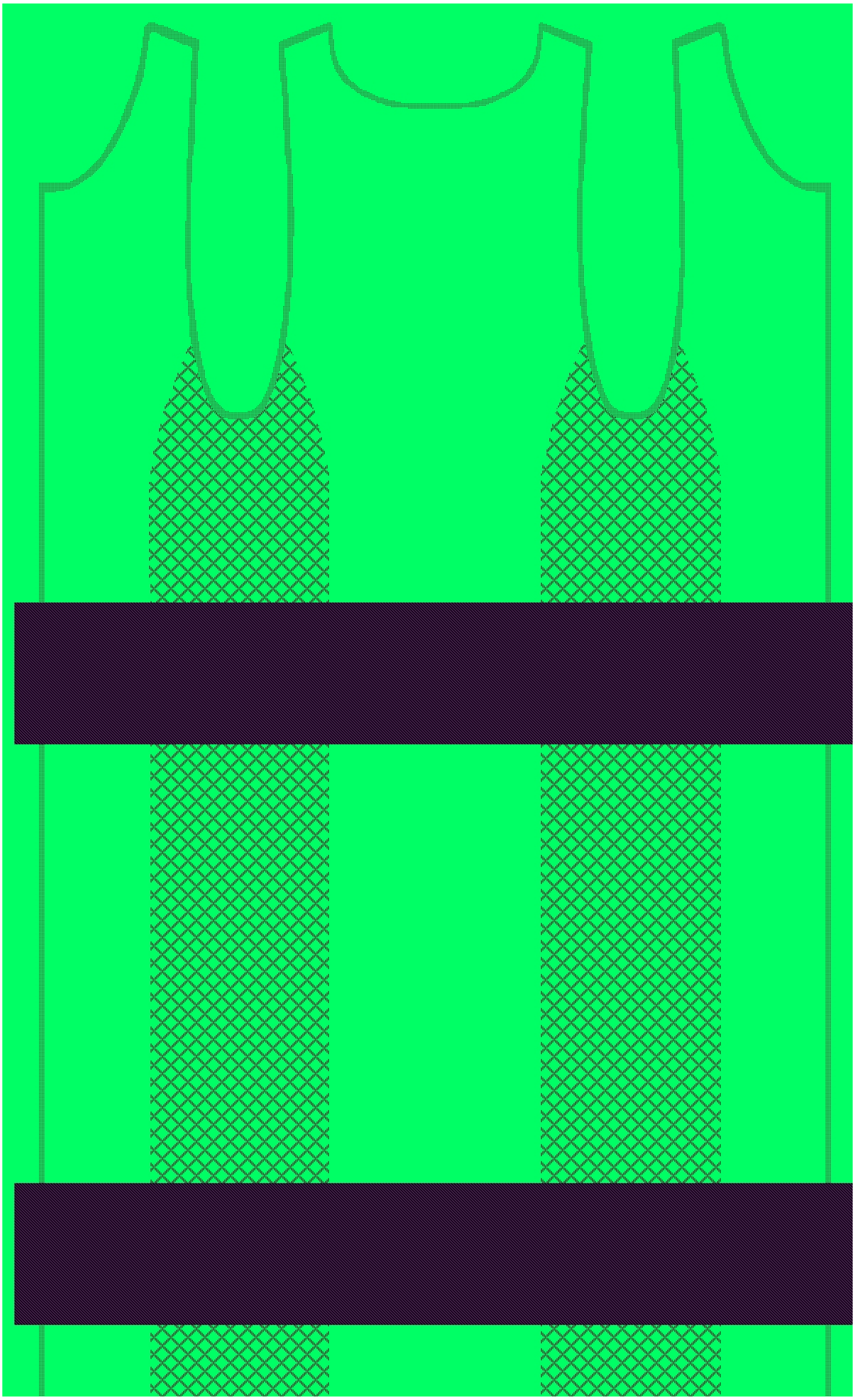
Sample #4



Sample #5

Sample #6

Sample #7



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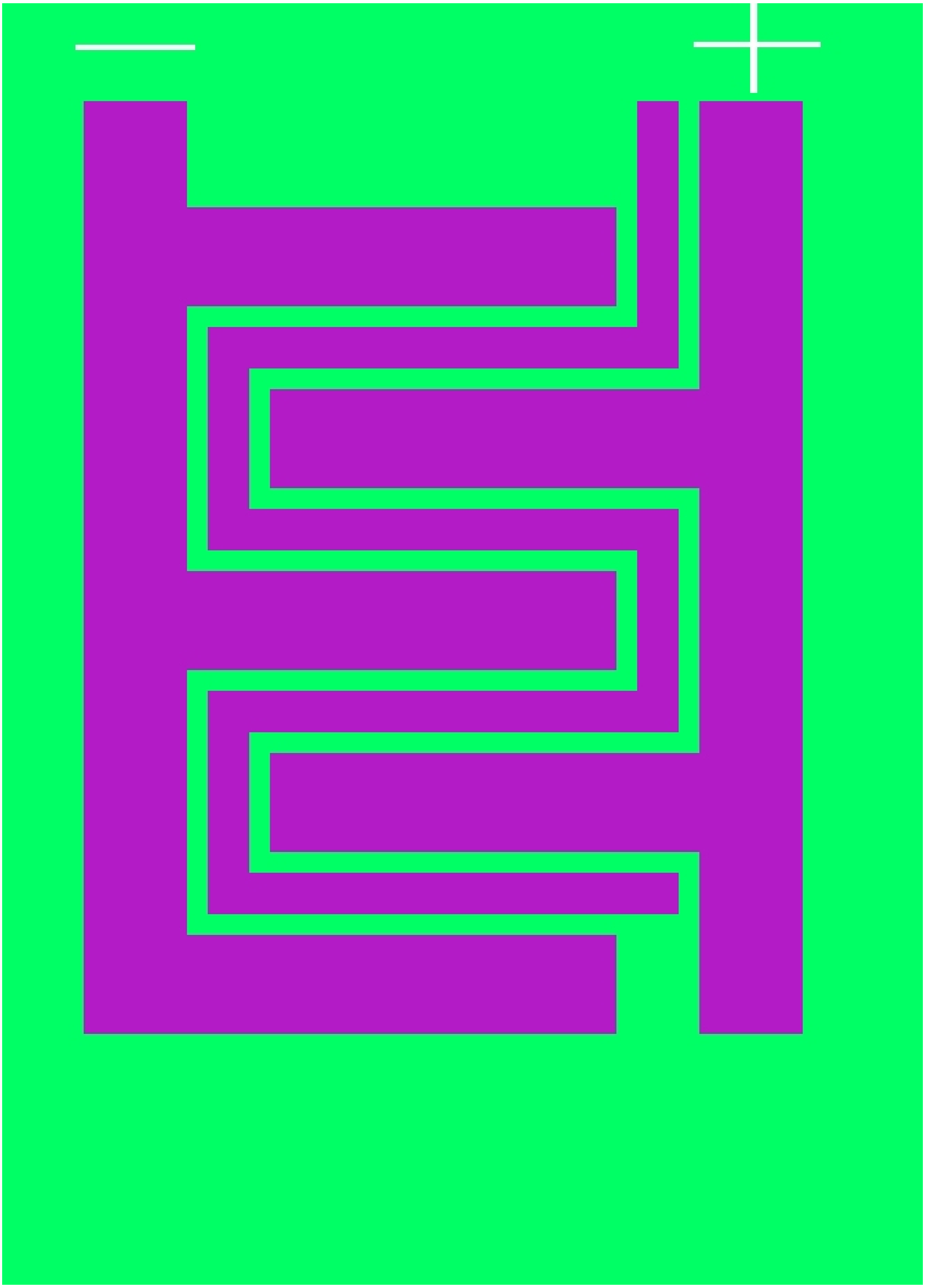

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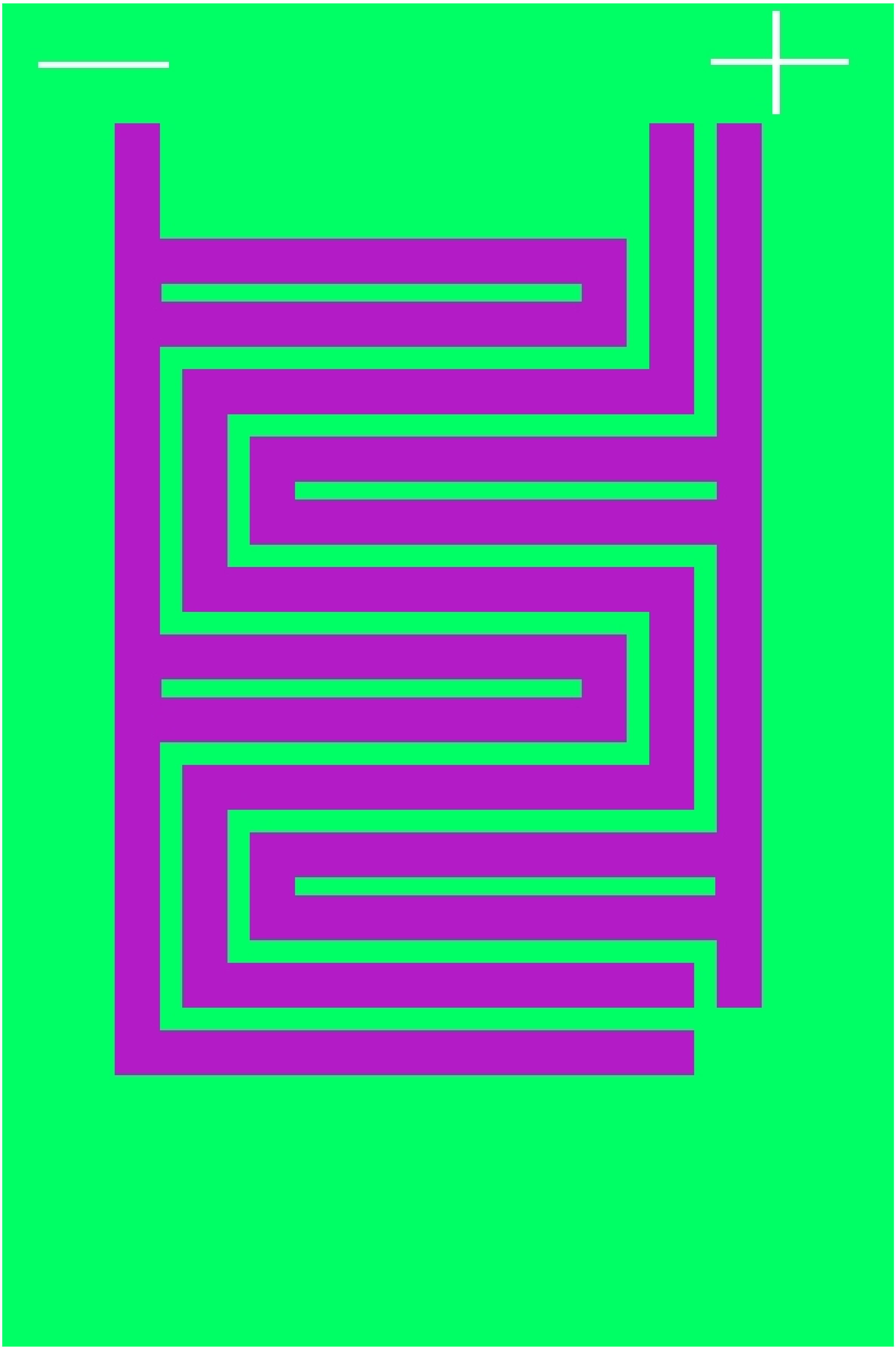

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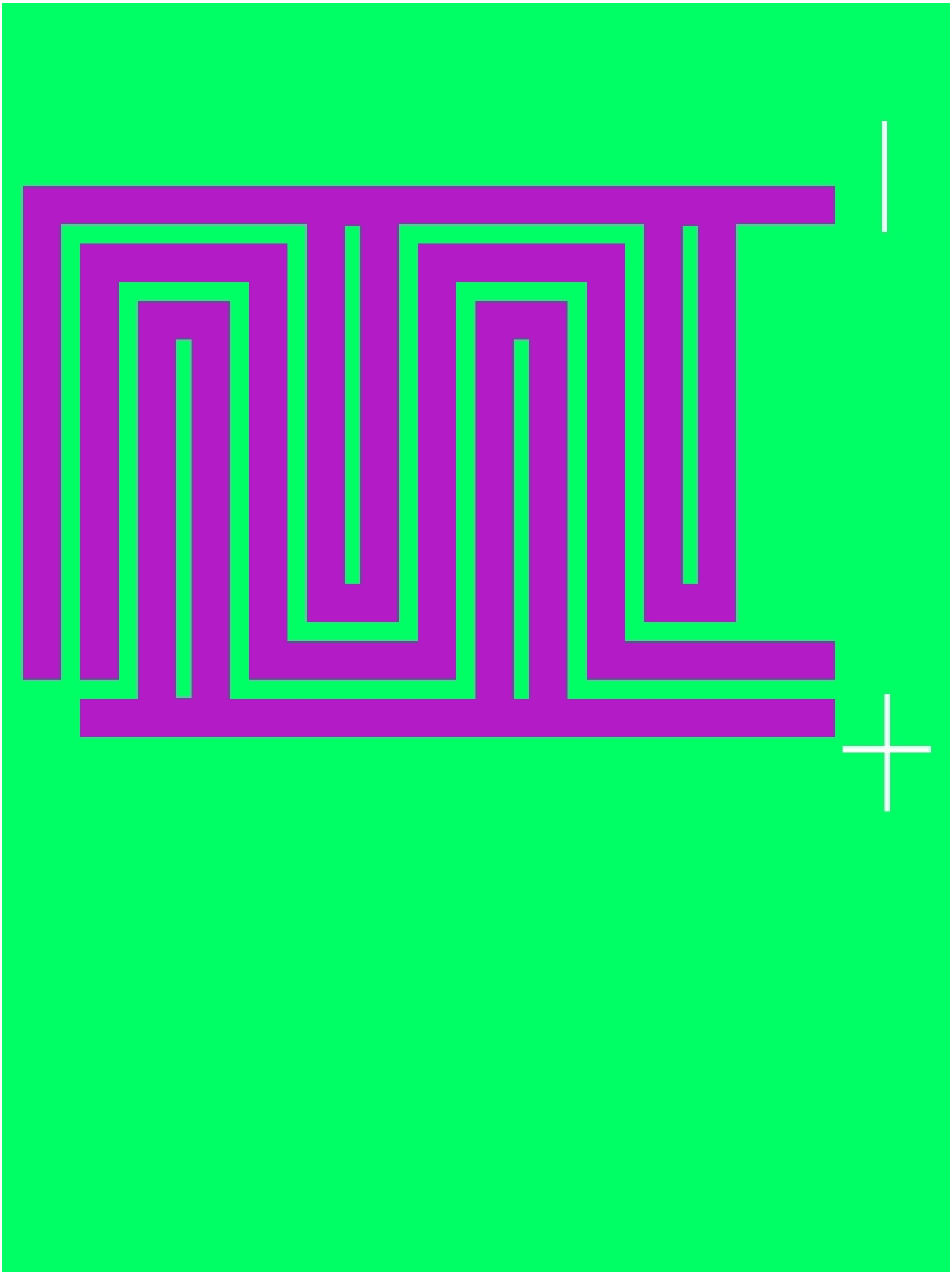

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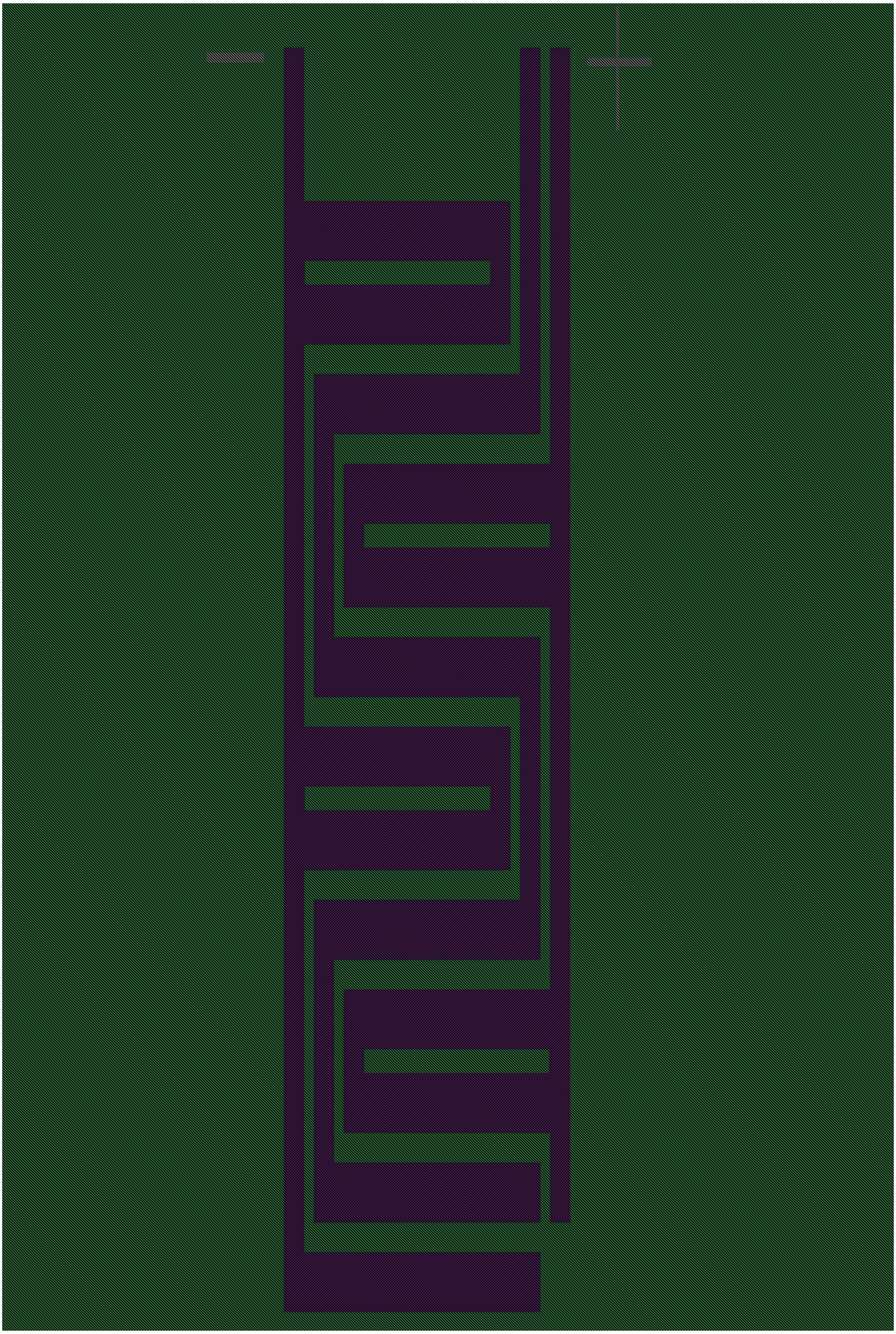
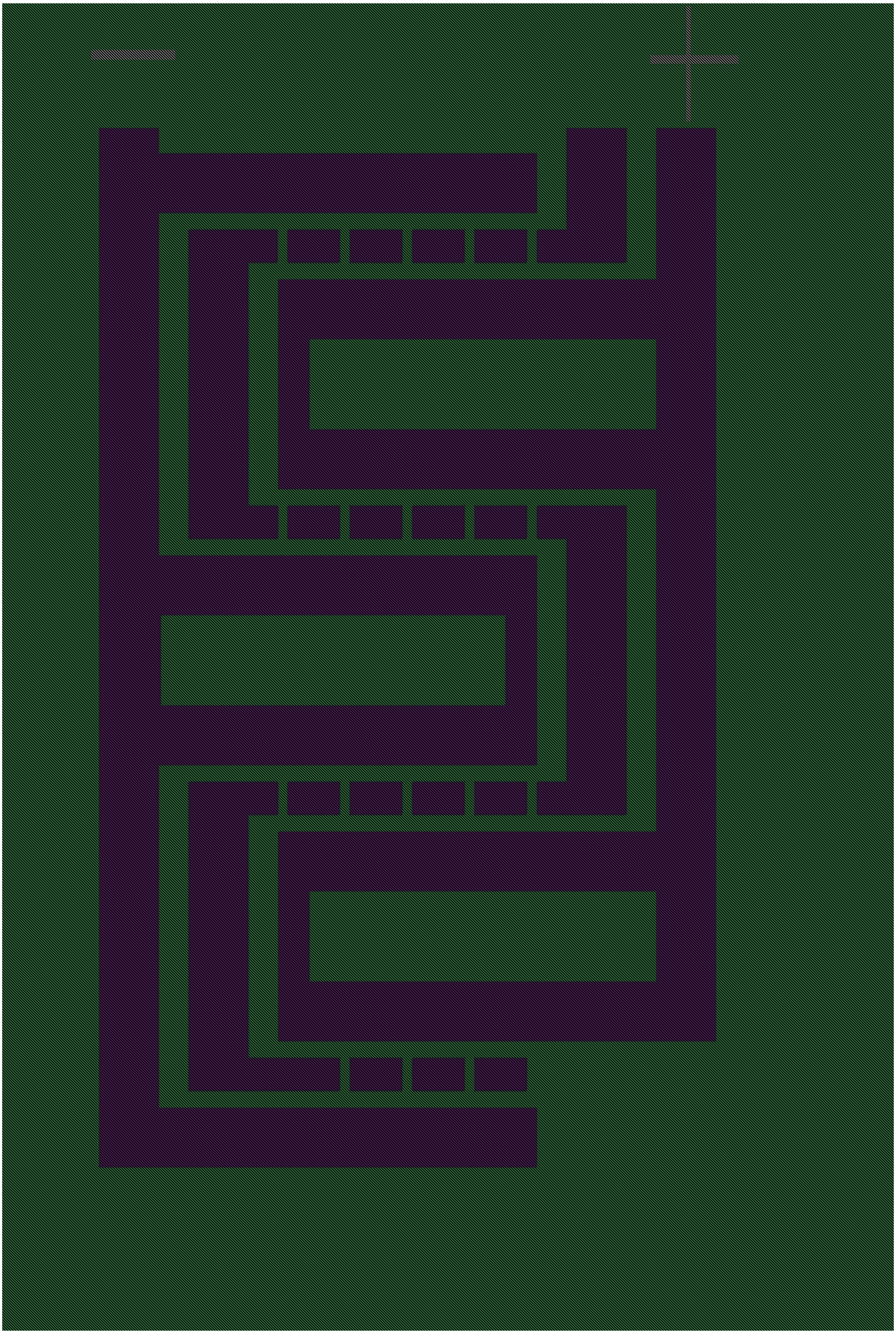


Sample #2.5



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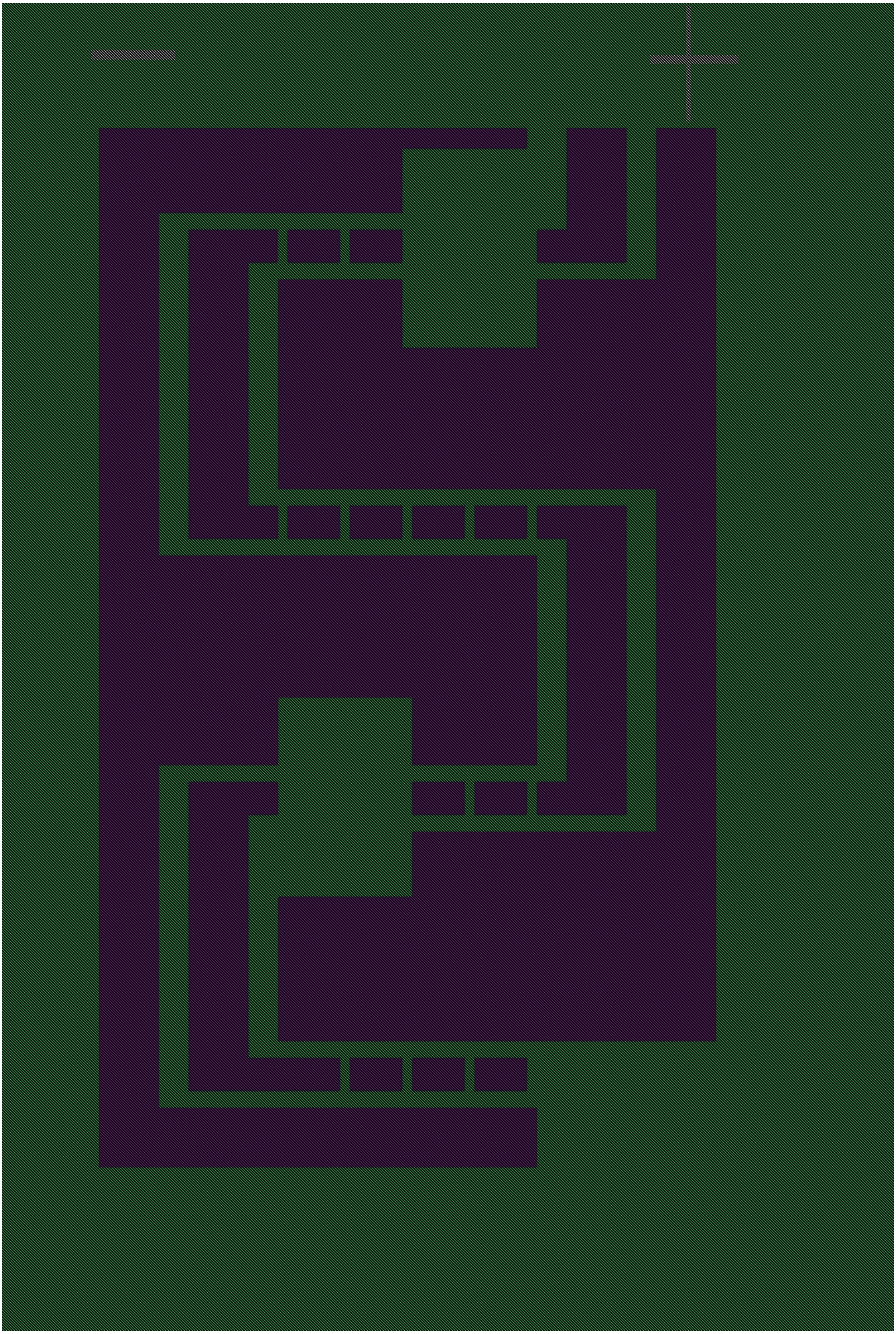


Appendix 3: Report on testing Breathpal readings using knitted strap

Version 1, June 2022 Author Ben Bulsink

Introduction

Breathpal version 3.1 PCB as presented on Breathpal.nl (June 2022) uses low resistance (<0,6 Ohm) straps. For the WBT project, knitted straps are used, which have a DC resistance of 6 Ohm or higher. To be able to work with these higher resistances, Breathpal electronics is adapted in a new prototype. This report lists the first measurement results.

Test setup and procedure

The electronics of one thorax sensor of Breathpal is adapted in prototype, to allow higher strap resistances. This sensor is connected to a knitted strap, with a variable resistor (0-50 Ohm) in series. The resistance of the strap itself is 6.1 Ohm.

The strap is placed around a carton box of 20.5 by 14.5 cm.

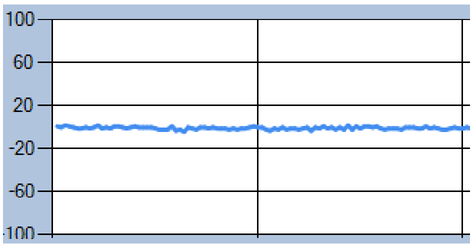
The Thorax sensor is connected to a Breathpal module, which is connected by USB to a PC, and data are sampled 10 times a second, and presented by Breath application.

The value R of the variable resistor is changed, the average reading (arbitrary unit AU) of the sensor is recorded, and the peak to peak noise is inspected visually and noted.

Results

R (Ohm)	R + R_strap	Reading (AU)	Noise	Remarks
0	6.1	22682	0	Switch closed
0.4	6.5	22831	0	
3.0	9.1	22943	2	
4.3	10.4	23003	1	
6.1	12.2	23080	1	
8.8	14.9	23198	2	
10.4	16.5	23257	4	
11.7	17.8	23313	5	
14.6	20.7	23427	5	See reading graph
16.6	22.7	23493	8	
18.2	24.3	23547	12	
20.9	27.0	0	0	No signal anymore – too high resistance

Reading graph at total resistance 20.7 Ohm



Note 1: See appendix 1 for an option to reduce the noise level at high resistances.

Note 2: The change of the Reading (AU) is not problematic, while the reading is an arbitrary unit by nature (see https://breathpal.nl/wp-content/uploads/2021/12/Breathpal-measurement-quality-report-vs-1.4.pdf). The sensitivity (AU per cm change of the enclosed surface of the strap) does not change much with changing of the resistance, but this has to be tested and qualified by a new series of test.

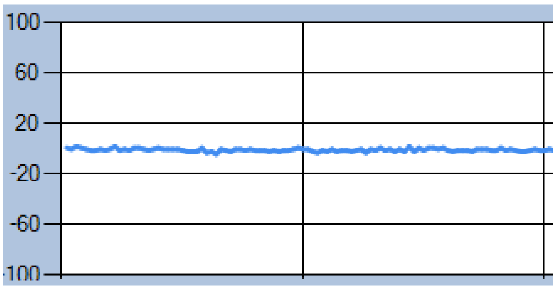
Conclusion

The adapted Breathpal electronics allow for straps up to 20 Ohm total resistance. The noise on the reading may increase by such higher resistances, compared to i.e. 6 Ohm, but further study and tests may reduce the noise at higher resistances.

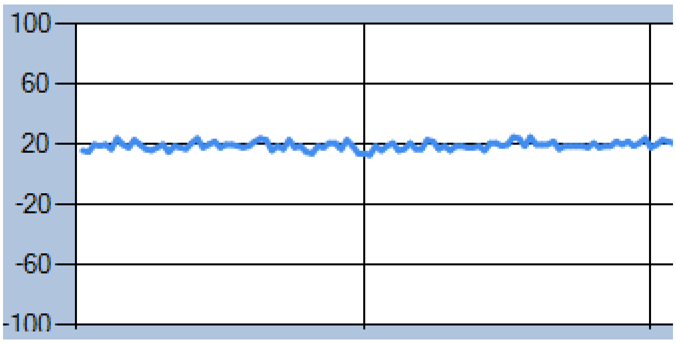
Appendix 1

The noise level appears to be dependent on a feature in Breathpal, called oscillator resync. This feature is set by Oscillator resync value. Below the readings at various values. All Reading graphs at total resistance 20.7 Ohm.

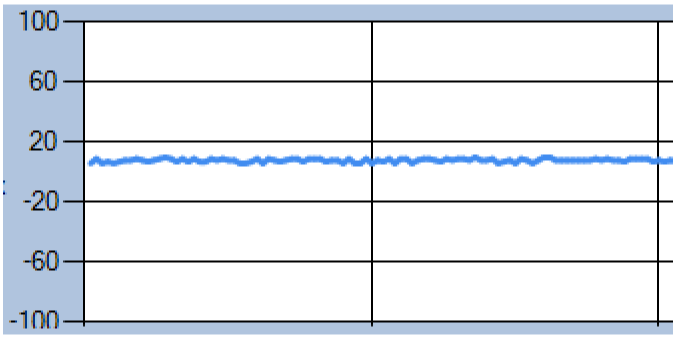
The conclusion is that for this implementation of Breathpal, the noise figure can be improved by setting the Oscillator resync value to 0 (zero)



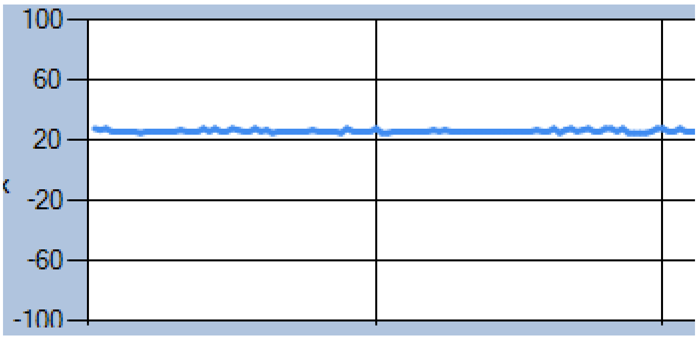
oscillator resync value 19



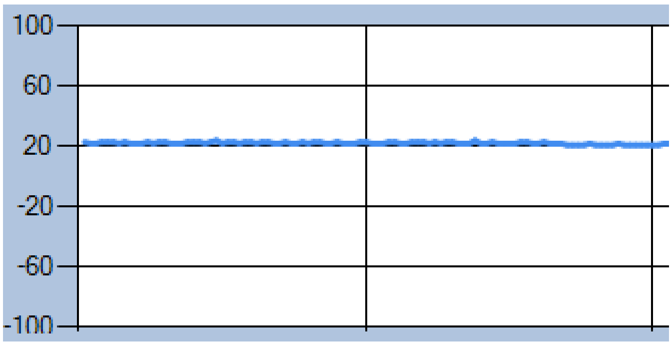
oscillator resync value 24



oscillator resync value 16



oscillator resync value 13



oscillator resync value 0 (no resync)