Exploring Moisture Management Inside a Fabric

Waterproofing a Garment From the Inside Out

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ABSTRACT

In this research, out group aims to optimize moisture management in wearable textiles to be used in a future of innovative fabrics that exist in multiple different contexts close to the body. Contemporarily, moisture management is usually viewed from the perspective that it is a task for the whole garment and its constituent materials. However, this research looks at moisture management through two unique lenses; human sweat management, and directional moisture management. The goal of this is to unify research and theorize a fabric composition or technology that allows a user to be dry on the inside and out, and to be able to use the moisture that their body comes into contact with on a day to day basis for practical purposes.

INTRODUCTION

Moisture management in textiles has long been a topic of keen interest in various industries such as athletics, fashion, deep-sea diving, space travel, and many more. People come into contact with various fluids on a daily basis, whether they be produced within the body, or a result of the outside world. We want to look and feel our best, as often as possible, but things like sweat, weather, food, and everything in between can easily come into contact with our clothes and make us lose our sense of cleanliness. Waterproof garments and technology are vital in modern outerwear, to protect against moisture from the outside world, while absorbent and wicking fabrics are useful when managing things like sweat. In space, water systems collect moisture from breath, sweat and urine and purify it into clean drinking water for astronauts [5]. Synthetic textiles like Neoprene are used for aquatic activities because they act as a total barrier between the skin and underwater environment. Things like diapers and tampons exist as sanitary means of moisture management. All of these materials do their jobs well, but are confined to a certain purpose, and aren't necessarily efficient.

After considering these technologies for a long time, our group came to some important realizations. The first of these was that most available and common moisture management technologies are only one-dimensional, in that they only attempt to lead unwanted moisture astray. We tried to imagine ways to actively control the directional movement of fluid, and were greatly inspired by things like reverse osmosis, and the membranous nature of cells or human skin, which actively move water through a surface and control whether it can move back or not.

Furthermore, moisture management usually comes in the form of controlling where moisture can move, but the group also identified that there could be benefits of keeping waste material such as sweat within the garment. New research has shown that sweat can theoretically be used as an energy source to power devices [1], can provide nutrients to plants [3] and be purified into clean water [2]. Although speculative, this research contributed to our groups preconceived notion of the potential to greatly increase moisture management techniques used in wearables. Expanding on this idea, we concluded that waterproof materials are great barriers that prevent liquid from entering the garment, but noticed that it is very difficult to allow moisture to escape from the inside. With this idea in mind, the group's research ultimately aims to explore the best material composition for a wearable textile that can optimize the various kinds of moisture distribution that a garment or base-layer can permit. Stemming from this, the group developed the coinciding research question; *How can we improve moisture transfer within a fabric with the aim of storing moisture inside of a fabric for later extraction?*

RELATED WORKS

The first article that the group looked at, which largely inspired our concept, was “Sweat Machine”. Developed by Andreas Hammar under a UNICEF campaign, this device purifies human sweat into clean drinking water using membrane distillation. The device collects moisture out of sweaty clothes via spinning and heating. It then filters the sweat through a GORE-TEX®-like fabric that allows only water vapor to pass through it. The less desirable bits, like bacteria, salts, clothing fibers and other substances get trapped within the filter. One person’s T-shirt can produce about 10ml of drinking water, according to this study.

Next, the group looked into “Temperature-Triggered Collection and Release of Water from Fogs by a Sponge-Like Cotton Fabric”. Here, Yang et al. [10] present a versatile and simple sponge-like cotton fabric which autonomously collects and releases water from a humid atmosphere, triggered by temperature variations within the typical day-and-night range of deserts.

Another research paper [6] we looked into described two types of directional water transport fabrics that are prepared by using cotton fabric as a substrate and an electrospraying technique to apply a hydrophobic coating on one side of the fabric. The main difference between the two electrosprayed fabrics is that one of them was precoated with a hydrophilic thermal conductive resin over the fiber surface prior to electrospraying.

A novel concept, introduced by Wang et al. [9], explores how preparing directional water transport cotton fabrics with high air permeability even at a fully wet state can be demonstrated. A two-step electrospraying technique is employed to form a superhydrophobic pattern array on cotton fabric at the first step followed by single-side electrospray treatment. This concept was “out there” from a technological standpoint, but inspired some of the materials purchased in our research.

In another article, written by Zeng et al. [12], it is proved that a hydrophilic fabric after being electrosprayed with a thin layer of hydrophobic coating on one side shows one-way water transport ability. By using moisture management tester, the water transport property is qualitatively characterized and the effect of hydrophobic fabric layer thickness on one-way water transport feature is examined. The one-way water transport is durable enough to withstand repeated washing. This novel fabric may be useful for development of “smart” textiles for various applications.

When exercising a body burns energy (glucose). To cool down the body sweat will leave the body. Sweat consists of water, salt, minerals and waste, such as lactate. Lactate can be used to generate energy using bio fuel cells. However, lactate is only present in sweat during the first 30 seconds to 3 minutes of sweating By an electrochemical reaction energy can be generated. The biofuel cells are flexible and wearable. The bio fuel cells have a power density of nearly 1.2 mW cm^{-2} at 0.2 V [1].

The body sweats the most on the back, forehead and shoulders [7].

METHOD AND DESIGN

The method and design was divided into two sections: Experiments concerning sweat collection are detailed in the first three experiments, and the fourth and final experiment explore membranous fabrics that mimic skin.

In order to harvest sweat non-invasively from the human body, sweat pads were envisioned to collect sweat from regions that secrete high volumes of sweat such as those mentioned previously. These proposed sweat pads were inspired by the composition and structure of diapers and sanitary pads as these wearables were specially engineered to collect waste fluids from the body. Diapers and sanitary pads are composed of three primary layers: Firstly, the wicking layer is usually composed of polypropylene and draws liquid away from the body and pushes it towards the absorbent core, keeping the skin dry. Secondly, the absorbent core retains the liquid, and lastly, the waterproof shell prevents any liquid from entering or escaping the pad [8].

Figure 1. Separated layers of a diaper. Wicking layer (top), absorbent core (middle), and waterproof shell (bottom)

While the envisioned sweat pads were seemingly imitative of diapers and sanitary pads, there exists a fundamental difference between the two in that the sweat pads should release moisture readily. Diapers and sanitary pads only provide a one-way moisture transfer by collecting and storing fluids, but are not designed to expel them. This is due to the presence of superabsorbent polymers (SAP) in the absorbent core that irreversibly absorb and retain water through hydrogen bonding with water molecules [4]. To harvest sweat, the sweat pads have to be able to first store sweat, and then at the desired time, release any collected sweat for the users. Therefore, SAP has to be completely removed and an appropriate material that allows for both absorption and release of liquid should take the place of the absorbent core. The next three experiments are concerned with testing different properties of materials that will ultimately come together to produce the optimal sweat pad.

Experiment 1.

Our first experiment was designed to determine the ability of different materials to readily absorb and subsequently release moisture repeatedly. Ultimately, this experiment aimed to identify the optimal material for the primary absorbent core for the sweat pads. Three absorbent materials - kitchen sponge, cotton and high-quality sponge, were tested in successive trials to observe their performance with continued usage. These three materials were chosen due to their common association with being absorbent and familiarity in daily usage.

Figure 2. Cotton (Top), Kitchen sponge (Middle), and High-quality sponge (Bottom)

A pad with dimensions 120mm (Length) x 60mm (Width) x 5mm (Thickness) from each material was produced and weighed before the experiment. The pads were then placed in a container of 50ml of water and left to soak the moisture for a duration of 5 minutes. After the specified time, each pad was weighed again to determine the volume of liquid absorbed by measuring the difference in initial weight and post-absorption weight. After weighing, the pads were squeezed thoroughly to the point in which no water could be released from the material anymore, and then weighed one last time to determine how much liquid was released from and retained in the pad. The materials were left to dry completely and then the experiment was repeated 3 times for each material to additionally test how effectively they perform over repeated usage.

Experiment 2.

The second experiment aimed to achieve the optimal wicking layer for the sweat pad. The wicking fabric from diapers were used during this test and several different treatments were applied to them. The aim of this experiment was to observe how different treatments on the surface of the wicking fabric affected moisture transfer. The wicking fabric was cut into sheets of 120mm x 60mm and were either left untreated or received treatments of waxing or waterproof spraying. Treatment was applied separately on the inner and outer sides of the wicking fabric to additionally observe if the sides of the fabric had an effect in moisture transfer.

The wicking fabric was placed directly over a measuring container and 5ml of water was dropped onto one side of the wicking fabric. The moisture transfer was observed and the volume of liquid that passed through to the measuring container beneath was measured. Additionally, the rate of moisture transfer was recorded to determine if the treatments retarded flow of water through the wicking fabric.

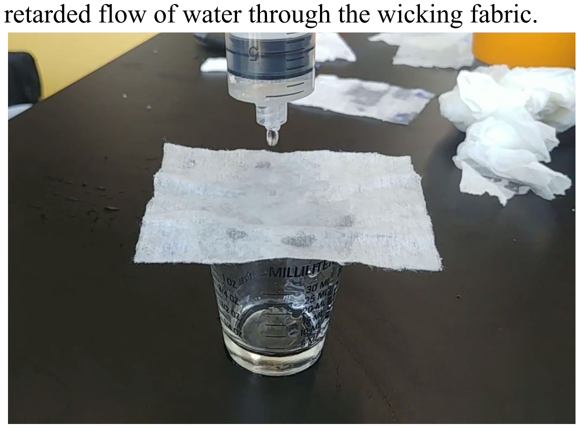

Figure 3. Setup of experiment 2. Water is squeezed onto the surface of the wicking fabric that is placed over a measuring container

Experiment 3.

This third experiment aimed to test the actual effectiveness of the designed sweat pads to absorb, retain and release moisture at the user's desired discretion. The final prototypes, which are a culmination of the results from the previous experiments, were put to the test and observed keenly. Two identical sweat pads were subjected to a test similar to experiment 1, where they were placed in a container of 50ml of water and left to absorb the liquid for a period of 5 minutes. After this duration, they were squeezed thoroughly to release the water.

What was different about this experiment was that the sweat pads were much more closely observed for how they retained water and expelled water. Both quantitative and qualitative data were gathered for this experiment, but with a greater focus on the qualitative factors. For example, from which area of the pad did water escape from and how did water release from the pad upon being squeezed.

Figure 4. Final prototypes of the sweat pads

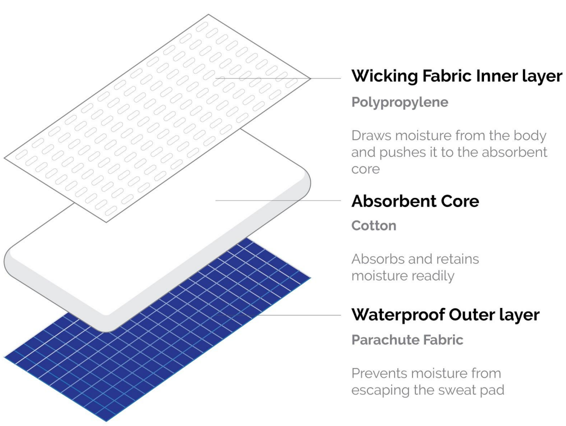

Figure 5. Sweat Pad Structure

Experiment 4.

The aim of this fourth experiment is to find a material or combination of materials that will mimic the membranous qualities of skin. More specifically, the way human skin sweats. We envisioned a fabric that would push liquid out from within and is waterproof on the outside, making liquid simply roll off.

This fabric would be applied as a wicking layer as described above.

An exploratory and iterative approach was taken to address this challenge. Some fabrics were taken that are known to have interesting properties when it comes to the way water moves through them. Ways of making fabrics water-proof were also considered.

The following fabrics were selected:

1. A plain white cotton cloth with a relatively tight weave.
2. A gauze-like cotton cheese-cloth, with a low thread count (grade #40).
3. A synthetic sports-fabric called dri-fit, claimed by Nike to actively wick sweat away from the body.
4. Parachute fabric; a very dense, tarp-like, synthetic fabric.

The first step was to test these materials and coatings to find promising properties. The procedure taken was as follows each time:

- Fabric samples of approximately 20x20 cm were cut.
- A drop of water was dropped on the fabric.
- The fabric was then lifted, held on it's side, and upside down.
- The whole procedure was recorded on video and the behaviour of the water was carefully studied by two researchers.

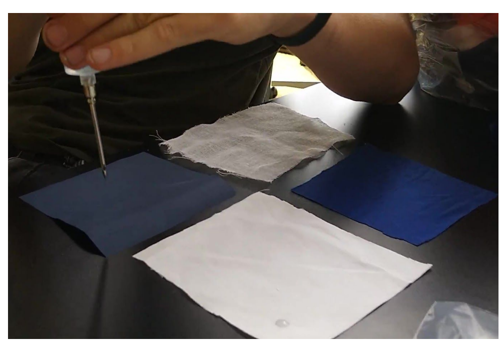

Figure 6. Experimental setup. Clockwise, starting left: Parachute fabric, cheesecloth, sports fabric, plain cotton.

For the second iteration, the effects of waterproofing one side of the different fabrics would have on the behaviour of water that came into contact with it. The first step of the procedure above was repeated, after which all fabric samples were coated with three layers of waterproofing spray before proceeding with the other steps.

At this point, a pretty clear idea of the properties of different fabrics formed and experiments took a more experimental turn. Pairs were formed of fabrics with interesting, promising and complementing properties. First was a hybrid of two samples of cheese cloth, prepared as followed: the sides of the cheesecloths that were touching (we will call these, the insides) were both coated in wax. This was a design decision made after multiple iterations of waxing the fabrics, and finding that waxing the insides of the material had the most potential for a controlled transport of fluid, rolling off of the fabric, instead of being absorbed. On the outsides (the sides not touching), one was sprayed, and one was left untreated. This was to allow some absorption, in hopes of achieving the desired effect; a membranous transport of fluid. Next, the experiment mentioned above was repeated by dropping water onto the untreated side.
The second hybrid was prepared by taking cheesecloth and athletic fabric. Again, the insides were waxed, the outside of the sports fabric was sprayed and the outside of the cheesecloth was left untreated. Water was dropped on the untreated cheesecloth side for the experiment.

RESULTS

Experiment 1.

In the first experiment the ability to absorb and release moisture was tested. The materials used are kitchen sponge, cotton and high quality sponge.

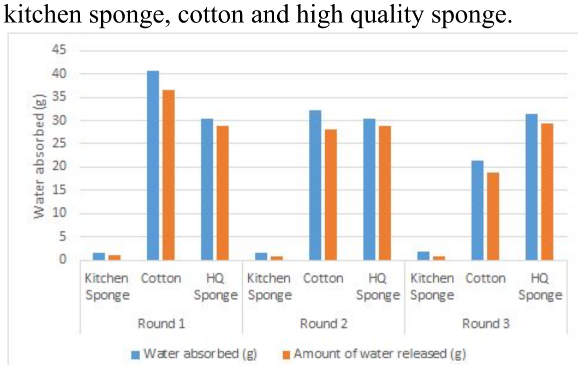

Figure 7. Absorption and release ability of test materials

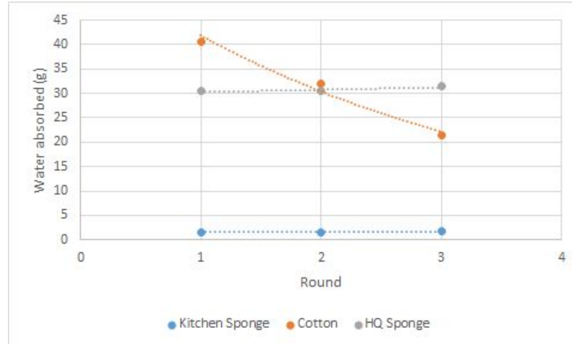

Figure 8. Absorption of test materials over repeated tests

As we can see in the graphs, the kitchen sponge is not able to absorb a lot of water and therefore could not release a significant amount of water either. The ability to absorb and release water is much higher for the cotton. However after every round the amount of water which is absorbed decreases. High quality sponge is not able to absorb and release as much as water as cotton, nevertheless high quality sponge keeps its ability to absorb and release water compared to cotton. After 3 rounds the structure of the kitchen sponge stays the same. The cotton becomes flatter and shrinks a little, however it stays flexible. The high quality kitchen sponge shrunk when dried and become extremely stiff, making it inappropriate to wear on the body. Hence, cotton was chosen for the absorbent core.

Experiment 2.

In this experiment we tested 7 different wicking fabric layers on both the inside (I) which touches the absorbent core, and the outside (O) which touches the skin. Fabric WI, which was waxed on the inside, Fabric WO, which was waxed on the outside, Fabric SI, which was coated with a waterproof spray, Fabric SO, which was coated with a waterproof spray, and Fabric U, which was untreated. For the WO and U Fabric both the conditions dry and wet were tested. The graph below details the results of the experiment.

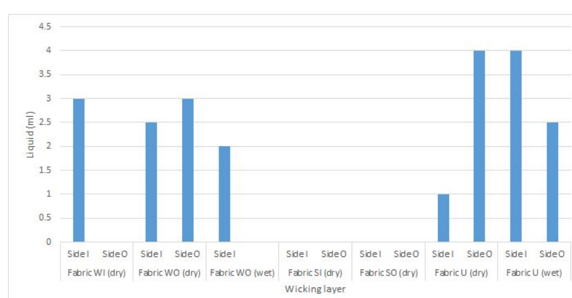

Figure 9. Graph of the results of experiment 2.

When 5 ml of water was dropped on the fabric, different volumes of the liquid penetrated to the other side. On Fabric WI (dry), Side I the water spread around the fabric very slowly and seeped through the middle and the edges. On Side O the water spread around the fabric very slowly and dropped off the edges. On Fabric WO (dry), Side I the water spread around the fabric and seeped half through middle and half from the edges of the fabric. On Side O the water slowly seeped through the centre and spread minimal around the fabric. On Side I (wet) the water spread around the fabric, most of the water seeped from the edges, a little water seeped through the centre. On both Side I and Side O of Fabric SI (dry) and Fabric SO (dry) the water collected in the centre and did not seep through. On Fabric U (dry), Side I, the water spread around the fabric and most of it dropped of the edges. On Side O of this fabric the water collected in the centre and then seeped through almost completely. On Fabric U, Side I the water seeped through immediately. On Side O the water spread around the fabric and seeped through the centre as well. Half of the water dropped off the edges and half of the water was collected in the cup.

This experiment revealed that applying the waterproof spray to the wicking fabric completely eliminated moisture transfer from all sides and hence, is not an appropriate treatment for the sweat pad. Waxing slowed down moisture transfer but did not indicate a significant difference in total amount of moisture transferred when compared to the untreated fabric, rendering wax a redundant treatment. The original untreated wicking fabric was thus chosen as the optimal wicking layer.

Experiment 3.

After absorbing water for 5 minutes both the pads had collected water. When putting them up side down the water did not seep out of the pads. Water could only seep out of the edges which is due to construction flaws of the pads itself and not the material properties. The wicking layer itself did not let water seep out. Only when the pads were squeezed did water release via the wicking layer, thus meeting the design goal of the pad. The quantitative results of the experiment can be found in the appendix.

Experiment 4.

Full qualitative observations on the initial stage of the experiment can be found in the appendix.

The parachute-fabric was completely waterproof in all tests, and for that reason less interesting for further studying. It was found that (the usually absorbent) cotton had the interesting property of becoming sticky to water after being sprayed with waterproofing spray. Cheesecloth and sports fabric both showed properties of (semi-) permeability, making them of special interest to our study.

The hybrid materials came very close to achieving the envisioned properties. Both behaved like a waterproof fabric to small droplets of water.

In the athletic fabric-cheesecloth hybrid, water moved through and soaked the fabric when large quantities were dropped on, but the material would be dry again when the water was shook off.

The cheesecloth-cheesecloth hybrid displayed interesting behaviour for larger quantities of water. Water would seep through and then stick to the bottom of the material in little droplets which could be shook off.

DISCUSSION

In the first experiment, we found that the cotton we used loses its ability to absorb water after repeated use. To make more reliable sweat-absorbing material, a way to prevent cotton from doing this should be researched. Another option is to pursue a high-quality sponge which does not become hard and brittle once dried.

The results of experiment two show a lot of variation, meaning the experiment might need to be repeated with larger surface areas and larger quantities of water.

Experiment three was quite informative and conclusive in the amount of water our sweat pads can absorb and release and created the opportunity for further calculations.

As briefly mentioned in the second paragraph of “Method and Design”, the intent of this research is the further development of a garment that will collect sweat to be used for various applications. To this end, a sweat-collecting undergarment was envisioned that is covered in a sweat-absorbing material similar to our sweat pad technology on the areas of the body that sweat the most [7]. Using data from our experiments as well as the existing literature we were able to make some calculations about the feasibility of such a suit.

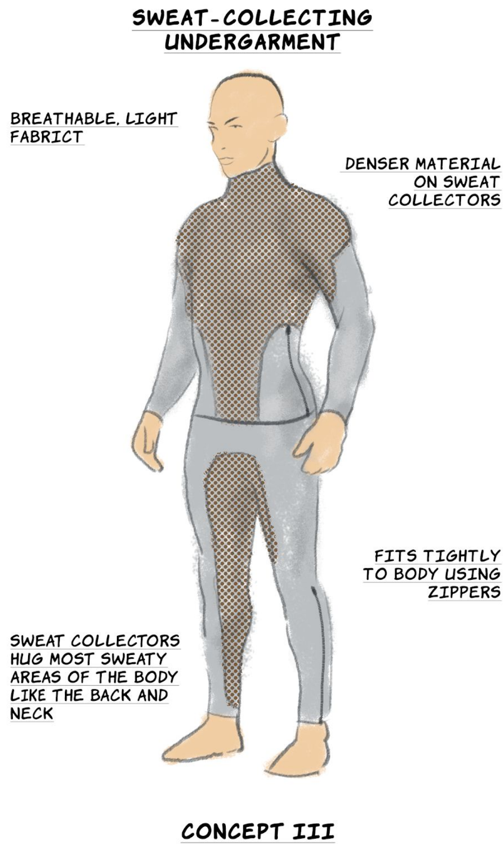

Figure 10. Proposed sweat collection suit

By pairing our research with research published in 2011 [7], how much sweat can be collected from a suit like this one after a set amount of moderate exercise can be estimated. The calculations can be found in the appendix**.** Based on the calculations it can be concluded that the area covered in sweat-absorbing material in the sketch above would be approx. 7746 cm². This area would produce approx 274 ml of sweat per hour. Our own experiments point out that when fully saturated, pads of that area would be able to contain approx 3.7 L of sweat and weigh roughly 4.2 kg. They would then be able to release 3.0 L of said sweat. The suit would however not be saturated with this much sweat till after 13.5 hours of light exercise, raising the question to what extend our small-scale experiments will scale up and be practical, since we did not experiment with partially saturated sweat-pads.

Note also that different areas of the suit would be saturated with sweat at different rates, and that the sweat might spread through the absorbent material.

CONCLUSION

To conclude, the group finalized multiple experiments and gathered enough data to judge our prior presumptions and develop new insights about the optimal moisture management techniques to be used in wearable textiles. In our first experiment, three absorbent materials were tested to compare the retention of absorbency after repetitive exposure and expulsion of moisture. It was ultimately deduced that cotton is a more appropriate material than spongy materials, because its material properties stay intact, as well as its absorbency, after repeated tests. In the future, our group would be interested in getting access to a multitude of higher quality or innovative materials that exemplify the modern state of absorbency in materials. Using the aforementioned methods, more experiments could be done, in more intense conditions, to widen the scope of what the envisioned sweat pads could do. In our second experiment, higher quality materials would have done well too. If the means to produce our own athletic wicking fabric were present, the group would be very interested in doing this, but in our current position, we could only make use of fabrics readily available on the market. Newer athletic fabrics are being developed all the time, and perhaps we could have made improvements in our experiments if we had access to them. After moving on to experiment three however, the group made improvements in moisture absorbency. The actual design of the pads allowed for some leakage, and this could have been improved. These same design decisions carried over to the fabric studies of experiment four, but were better executed (parachute fabric lining).

An overall conclusion that can be made about each experiment, is that they all could have turned out better with better materials, but they all succeeded to indicate to us that there are numerous ways in which typical fabrics can be utilized and optimized for moisture absorption and expulsion. After treating the fabrics in a number of ways, it was easy to tell that they were capable of more than expected, using an understanding of hydrophobic/hydrophilic substances. In Figure 10, we proposed a grand unification of the implications of our research, in one design. Although speculative, this idea presents a successful outcome of a design research scheme; that being a proposed design born out of initial designs and coinciding research. We are satisfied with the work that was put into this research, and remain inclined to monitor, contemplate, and speculate about the implications of our research and other new research on the future of moisture management in wearable textiles.

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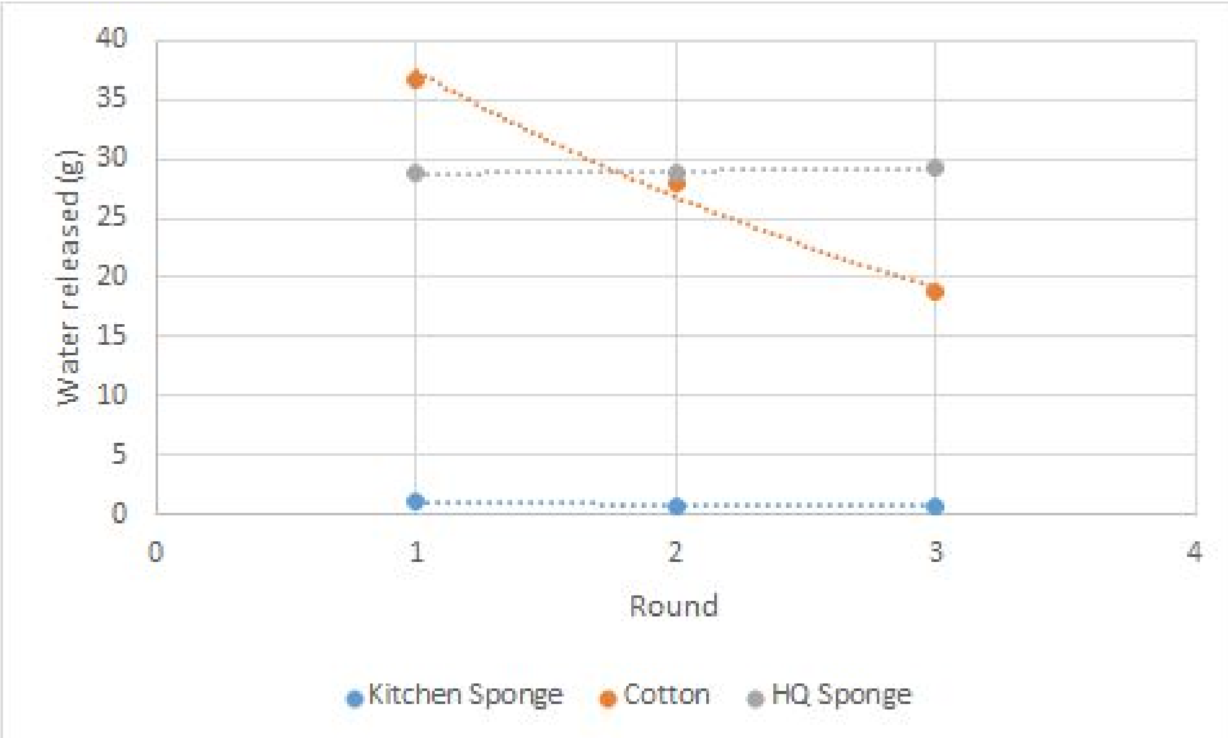
APPENDIX

Full results experiment 1

Round 1	Pads		
	Kitchen Sponge	Cotton	HQ Sponge
Weight before soaking (g)	1.0	1.9	3.5
Weight after soaking (g)	2.6	42.6	33.9
Difference (g) = Water absorbed	1.6	40.7	30.4
Weight after squeezing (g)	1.5	6.0	5.1
Amount of water released (g)	1.1	36.6	28.8
Water retained (g)	0.5	4.1	1.6
Round 2	Pads		
	Kitchen Sponge	Cotton	HQ Sponge
Weight before soaking (g)	1.0	1.9	2.7
Weight after soaking (g)	2.6	34.0	33.2
Difference (g) = Water absorbed	1.6	32.1	30.5
Weight after squeezing (g)	1.8	6.0	4.3
Amount of water released (g)	0.8	28.0	28.9
Water retained (g)	0.8	4.1	1.6
Round 3	Pads		
	Kitchen Sponge	Cotton	HQ Sponge
Weight before soaking (g)	1.0	3.2	1.9
Weight after soaking (g)	2.8	24.7	33.3
Difference (g) = Water absorbed	1.8	21.5	31.4
Weight after squeezing (g)	2.0	5.9	4.0
Amount of water released (g)	0.8	18.8	29.3
Water retained (g)	1.0	2.7	2.1



Full results experiment 2

Fabric	Side	Volume of liquid that passes through (ml)	Observations
Fabric WI (dry)	Side I	3	Water spreads around the fabric very slowly and seeps through the middle and edges
	Side O	0	Water spreads around the fabric very slowly and drops off the edges
Fabric WO (dry)	Side I	2.5	Water spreads around the fabric, half seeps through middle and half from the edges
	Side O	3	Water slowly seeps through the centre, minimal spreading around fabric
Fabric WO (wet)	Side I	2	Water spreads around the fabric, more of it seeps from the edges. Some seep through the centre
Fabric SI (dry)	Side I	0	Water collected in centre and did not seep through
	Side O	0	Water collected in centre and did not seep through
Fabric SO (dry)	Side I	0	Water collected in centre and did not seep through
	Side O	0	Water collected in centre and did not seep through

Fabric U (dry)	Side I	1	Water spread around the fabric and mostly dropped off the edges
	Side O	4	Water collected in the centre then seeped through completely
Fabric U (wet)	Side I	4	Water seeped through immediately
	Side O	2.5	Water both spreads around the fabric and seeps through the centre, half drops off the edges and half is collected in the cup

Full results experiment 3

	Sweat Pads	
	Pad 1	Pad 2
Weight before soaking (g)	4.6	4.4
Weight after soaking (g)	39.0	40.8
Difference (g) = Water absorbed	34.4	36.4
Weight after squeezing (g)	10.9	10.7
Amount of water released (g)	28.1	30.1
Water retained (g)	6.3	6.3

Full results experiment 4

	Untreated	Treated
Parachute	Stays a small bead on top of the fabric. Does not stick and rolls right off.	No significant difference
Sports fabric	Stays a small bead on top of the fabric. Sticks a little bit, but does roll off when agitated.	Is a bead initially, then seeps right through the fabric to the surface below quickly, leaving a slightly wet patch as big as the drop itself which dries quickly. Some drops stay on the surface and roll off.
Cotton	Absorbs into the fabric, creating a wet patch much bigger than the initial drop.	Droplets are beady, do not seep into or through the fabric and are very sticky. Will not roll off but instead stick to the fabric even when flipped or agitated.
Cheese cloth	Is a bead at first, but almost immediately seeps through to the other side	Droplets are small beads on top of the fabric that roll off when agitated.

Calculations of sweat produced by hour by the body in certain areas
based on source [11]

	area	sweat produced	no. of pads	sweat produced
	cm²	g/m²/h		ml/h
shoulders	689	267	2	37
lat upper chest	366	262	2	19
centre upper chest	370	318	1	12
lat mid chest	372	244	2	18
centre mid chest	186	370	1	7
lower chest	171	174	1	3
lat upper back	425	515	2	44
centre upper back	235	707	1	17
lat MU back	203	431	2	17
lat ML back	191	322	2	12
centre mid back	195	771	1	15
med upper leg	735	166	2	24
ant med lower leg	557	352	2	39
neck	322	288	1	9
Total	**7746**			**274**

Calculations of water absorbing capabilities of suit:
Based on the surface area of the pad and the sweat-absorbing surface area of the suit, the following values were extrapolated:

	area of pad	weight of pad	wet weight	water absorbed	water released
Units	cm²	g	g	g	g
experiment	72	4.6	39	34.4	28.1
suit	7746	495	4196	3701	3023

Additionally, it would take approx 13.5 hours of sweating at the rate associated with light exercise [11] to fill the suit.

REFLECTIONS

Thijs:

Finding a subject

This project has been quite a turbulent one. Our team switched topics multiple times. We were always very interested in learning and working, but I think that we were not quite able to translate our efforts into a research question or format. We initially ventured out to research the feasibility of implementing the zip-loc system in clothing, then transitioned to creating a suit for the biofuel cells described in one of the sources of our paper [1], after which we wanted to do a broad research on moisture management in clothing. Ultimately our paper focuses specifically on methods to temporarily store sweat in fabrics for later extraction.

Teamwork

Working with Rishi, Zeno and Ian has been a pleasure. As a team, we have hit quite some moments of creative block, uncertainty, confusion and general low energy but I am happy to see everyone stuck with the project and with the other team members till the end. I think that all team members felt a bit tired or low in energy at times and that we all were also susceptible to the contagious effects of this. Feedback we often got during squad meetings was that we looked tired or depressed, which did not really help our case. We have all had moments where we were critical of other group members. In these moments I learned that it is important to hold back on blaming your group members and to try to focus on what you need from them and what they might need from you. Doing this, I have offered help preparing for the demoday, conducting experiments and more.

I think the decision to split up towards the end was a pivotal moment and did cause more productivity in all team members. What also really helped me was to talk about some of the underlying concerns that caused the difficulties in maintaining a working attitude for some team members. Being on the same page about this helps manage expectations and create a healthier group atmosphere.
In my opinion we made the most progress in the last few weeks, where we knew where we were headed and we knew who was pursuing what.
I would like to add that for me, this was not a passion project. I am not a fan of hardcore research and data gathering if it does not serve a practical design. I was very invested in my P2 project, leading to the opportunity to develop it further in collaboration with our client. This means that during the project I have at times also been preoccupied with finishing and deploying this previous project. It has been a hectic time the past half year, but I also learned a lot.

Development

I was able to develop a lot of competency in the field of doing research. Opposed to previous courses, which were mainly on doing user studies, this research project offered the opportunity to do more material research. I learned a lot about conducting experiments and gathering quantitative and qualitative data on different material properties and making design decisions based on those properties; an important skill that has up until now gone mostly unaddressed in my studies.

My interest in the production of garments and the prospect of sewing, embroidering etc. was one of the reasons for choosing this squad. The directions our team took and the fact that this project focused on research instead of product design made it so that I got to use those machines and techniques less than I would have hoped.

I did get to work extensively with the 3D-printer, meaning I taught myself Autodesk Fusion 360 to create 3D models and familiarized myself with the different concepts, settings and materials used in the 3D-printing process. This course introduced me to this manufacturing technique and already I have found multiple uses for being able to produce and prototype 3D models in various other cases. I expect this to be a very valuable asset in the future.

Rishi:
Designers are creatures of habit, and as I have progressed through my education as an ID student at TU/e, I have remarked on this fact many times. This is largely because I've caught myself resisting change so many times, and Project 3 was one of the biggest changes I had to acclimate to as a designer. As someone who is primarily interested in the expertise area of Creativity and Aesthetics, the idea of being in a research group did not seem particularly exciting or interesting. I was afraid that I would not be able to express my creativity well, which is the main reason why I wanted to become a design student in the first place. Upon meeting with my group, I became further skeptical because I had never been in a group with only males before. This struck me as something that could turn out to be a sort of stagnant dynamic that would not translate well to a successful project outcome.

It took our group quite some time to get the ball rolling on potential concepts to research and brainstorming mechanisms. We had formed because of our shared interest in aesthetics and materials, but I feared that my skepticism would be justified if it would go on any longer. However, I was surprised at the room for creativity a design research project presented. We made a Pinterest board, and it was interesting to bounce ideas off of each other that were related to how we formed as a group. We were at first very interested in designing mechanisms for closure in garments, that could improve on the flexibility of them. We played around with typical materials, and even made some 3D prints, but this idea quickly became a dead end after receiving various criticism on Friday tutor sessions. Our group was very sensitive to criticism, and we endured a long period of changing research topics to try to conform to what we thought was expected of us. This was a mistake in hindsight.

I am greatly pleased by the fact that our group was able to put our heads together to focus our energy onto a topic that was feasible. We hovered around in a cloud of confusion for a while after abandoning our closure mechanism ideas, and this cloud was centered around material studies related to waterproofing. We even hypothesized new means of designing rainwear, but saw little room for new research to be done. I remembered reading something about reverse osmosis in high school Biology class, and tried to relate it to the direction we were heading with our brainstorming. At first I was hesitant to bring up the idea at all, and it was met with mixed enthusiasm from the group. Ian and Zeno had creativity ideas about moisture absorption in textiles, while Thijs was interested in what I had to say about a biological approach to designing for wearables. The combination of these ideas was difficult at first, but I am glad that we managed to offer ideas to each other that were new and refreshing, and reaching for serious innovation. We acknowledged that materials like Gore-Tex existed, but persisted on trying to engineer a fabric that could be close to the skin with greater utility. We based our research around this idea, and even hypothesized uses for the moisture that a human body comes into contact with.

Come demoday, I was pleased to present all of the research and experiments the group did, and felt confident in my ability to explain why it was useful. I have given many pitches before, as a native English speaker, but I had never in my life explained detailed research to eager listeners. I was pleasantly surprised at the curiosity of many spectators about our research relating to speculative uses for sweat collection. However, our tutors warned us that these uses were very theoretical, and that the focus of our project and research paper should remain within the confines of our experiments and hands-on research. This was an agreeable conclusion to our group, but we are still confident that there are many implications of our moisture management research on the future of wearable textiles. I believe that we could make a host of new conclusions with more access to expensive or scarce fabrics and technologies. It would be very interesting to try to fully realize our proposed suit that unifies all of our research, and I do not think this lies beyond the realm of feasibility. The way we dress will undoubtedly be very different in the future, and I am curious to see where our group's research fits into that picture.

Ian:
Just before the semester started, I was thrilled to learn that I was enrolled into DFP002 and was given the opportunity to work with soft materials in a research-driven project. Coming from the National University of Singapore (NUS), where there is a heavy focus on digital rendering and presentations, I was excited to finally have a change in design approach to something more hands-on and exploratory. Academically, I wanted to learn how to appropriately conduct material-based design experiments, which is something I have not been exposed to before, and ultimately produce something unique that stimulates our thinking. Furthermore, broadening my design attitude and practices through cultural exchanges with Dutch and other international designers was an important goal for me.

With regards to my contributions to the project, I played a large role in pursuing physical exploration by conducting experiments to gather meaningful data and further our research. I designed most of the experiments regarding the sweat pad exploration and adopted a structured approach by testing materials in a successive order. This means that each designed experiment aimed to qualitatively and quantitatively analyse, and improve upon a small element of the prototype so as to produce the most optimal product in the end. In terms of documentation and writing, I was responsible for writing most of the draft research paper as I was confident in drafting academic reports, due to my experience in NUS. As my group members experienced difficulty with writing the draft paper, I took it upon myself to step up and set a standard for the report that we could potentially follow and improve upon for the final report. And as I was most deeply involved in designing and executing experiments for the sweat collection, I was responsible for writing the method and design sections in the final report. Additionally, I was also responsible for presenting our project to the assessing tutors at Demoday alongside Rishi.

Reflecting on my personal experience across the semester, I have definitely had a very bumpy journey full of barriers and breakdowns. But because of this, I feel like I have learnt a great deal not only about academic design testing, but also appropriate people-interaction in a group setting. Through the rich physical experimenting and exploration that I have done, I have learnt that materials can often act in ways that one does not expect and while this can be unfavourable for the research, it can sometimes be an exciting breakthrough. This uncertainty made the process fun, and unexpected results always fuelled my motivation to delve deeper into the material exploration to uncover underlying properties.

In terms of working in a team, it has been a challenging process as the working attitudes in Singapore and the Netherlands is vastly different and hence it was no surprise that I experienced culture shock. In the first quartile, I was completely out of my comfort zone and did not know how to effectively communicate with my group members or steer the project in a meaningful direction. I felt unhappy and alone just because they did not work in the way that I was accustomed to. However, with time and support from my teachers I realised that perhaps the problem was not my group members but within myself; I had to look inwards to make a change and worked towards being more patient and open-minded with my group mates. It was then that I started to gel with them and make great progress in the project. I feel that through this project, I have become less rigid in my thinking and more receptive to ideas that I would have previously dismissed as wild and far-fetched.

I am confident that the skills I have learnt in this course will be valuable to my future design practise as they are highly transferable and applicable across a wide range of project types. The rigour and structure that comes with conducting iterative experiments on materials can be used in different tests such as prototype and user testing. Additionally, the people-skills that I have gained through having such a challenging experience with group mates from a different culture has definitely made me a more resilient and open-minded designer as a whole. On the whole, I am very proud to have overcome seemingly insurmountable challenges that plagued the journey, and I am grateful that this experience has led me to grow and mature as a designer.

Zeno:
The second semester of my second year industrial design bachelor I worked on Project 3. This research project was done in the Creating Everyday Soft Things squad. During this project we were first coached by Marina Toeters in the beginning who was followed by Rong-Hao Liang after a few weeks. We also got a lot of coaching of Kristina Andersen who helped us a lot with finding what we wanted to do research on. We did researched on the optimization of moisture management. We therefore conducted multiple experiments with different materials in various conditions and combination. Before I started with this project I did not have that much of prior knowledge of waterproof materials, wicking fabrics and moisture management in general. I expected for this project to apply and develop skills in the area of Technology and Realization. For example making garments, gaining knowledge about (soft) materials and 3d modelling and printing. Above that I expected to improve my skills in the area of Math, Data and Computing by analyzing the gathered data of our research. My goals for this project were developing these expertise areas and becoming more educated in Design and Research Processes which is an important part of the competency framework. Next to that I wanted to develop and improve my professional skills, especially working together with and directing a group of different people . In order to improve my communication skills I wanted to enlarging my English vocabulary during this project.

At the beginning of the project we had some difficulty in the initial phases of our research project. It was not the case that we did not do a lot, but we just weren't able to get to the research direction we wanted. After diving into closure systems we pointed our attention to zip locks. We made some 3d models using Fusion360 and Cura+ and then tried to print soft zip locks using the Ultimaker 2. We also printed 3d molds in order to make soft, flexible zip locks using silicones and latex. Next to that I made some iterations of the zip lock system implanted into garments. Although we didn't continue doing research on zip locks and 3d printing I already learned a lot like how to do basic 3d modelling and printing. We continued our research on finding and designing future context in which zip locks into garments would be useful. This eventually turned into the research on moisture management. From this point we started conducting experiments with different materials and gathered data and results. I learned about conducting scientific experiments and analyzing data.

With the final research direction we did not go very much in depth. This is due to the fact that every time we got stuck in the direction of our research we shifted the direction instead of pushing further. We should have looked for more research about the subjects and ask more and different experts. Although people and coaches told us to try dive deeper into the subjects to find something which is we were really interested in. This something I would point more attention to future projects.

In the group work we had some troubles as well. I think a lot of moments we all had hesitating attitudes towards the research direction. In earlier project I could manage to get an overview of what we do and what we want in order to guide the group in the right direction. Unfortunately I wasn't able to accomplish this role. I think this was due to my vocabulary and communication skills in English. Sometimes I had the feeling that I did have the overview, but then I still couldn't reach the individuals in the group. Although this did not go as I wanted to, I learned a lot about working with a varied and difficult group.

After splitting up the research I worked together with Ian. We conducted lots of different experiments. For demo day I made the branding for our demo. We worked on several posters and made the water tap application example with custom cups together with Thijs. Although it looked all good in my opinion it eventually these things distracted the demo from the research part which was most important. During this project I improved my skills in the area of Technology and Realization, Math Data and Computing, Design and Researched Processes and Professionals skills as described above.