# Wear Your Heart on Your Sleeve:

## Using Digital Knitting Machines to Craft Wearable Biodata Portraits


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### ABSTRACT

Biofeedback sensors that measure body signals, such as heart rate, are often used for bodily awareness and behavioural change. In contrast, for this project, we wanted to use body sensor data as an artistic resource to craft wearable textile portraits as mementos of a moment in time. During the pandemic, we conducted a user study to design knitted biodata portraits. We met up individually with 20 participants to measure their heart rate, and translated that data into digitally-designed aesthetic patterns for machine knitting. Using a hacked knitting machine, we fabricated these patterns to create 20 personalized wearable shrugs to enable individuals to "wear their heart on their sleeve". Two years later, when it was safe to do so, we conducted 2 studio workshops with participants, followed by 10 individual interviews. Our qualitative study insights reveal how individuals felt about seeing their own biodata, and the biodata of others, as aesthetic machine-knitted wearables with perceived precious value and attachment.





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### CSS Concepts

• Human-centered computing~Human computer interaction (HCI)

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### BACKGROUND

In previous research, feelings towards heart rate and biofeedback sensing vary to a great extent depending on the context and how the data is presented. Visualizing and sharing heart rate as a number can feel overly revealing and risky [60]. These feelings come from society's perception that biofeedback can be an "authority" revealing emotional state or stress level [34, 60]. Current commercial trends in biosensing often include applications that focus on optimization and enforcing norms, encouraging certain behaviours and

discouraging others [32]. Researchers have highlighted the need to avoid framing biodata as "truth" [67]. Instead, our biodata is open for interpretation and can be something that we collaborate and live with [59, 67].

Designers often use ambiguity or anonymity to help individuals feel more comfortable with heart rate sharing [35, 49, 68, 69]. Ambiguity forces viewers to be active participants in the sense-making process, so rather than systems telling individuals directly about what their biodata means they must instead interpret it through their own experiential lens. For example, many artists create aesthetic, calming environments with scenes from nature [19, 38, 74] or create wearables and objects that demonstrate subtle changes in response to biofeedback [13, 61, 70, 73, 75].

Researchers are increasingly exploring how biodata can be used in more diverse ways, for example, in a playful way for self expression [65]. Previous work has used biofeedback to activate kinetic wings [28, 29], to make wearables that "twinkle" to augment social cues [33], or to capture and celebrate laughter with physical sculptures [58]. Body data can also be used for design memoirs to help individuals record difficult times or periods of struggle [17, 18]. Rather than using biodata to optimize and "fix" us, these designers demonstrate how biodata can be used to celebrate or commemorate.

For the Research through Design project 'Wear Your Heart on Your Sleeve' we were interested in further exploring along the lineage of artists using heart rate as a design resource to control variables or aspects of artistic outputs (such as controlling the aesthetic design of 3D models [41–43], paint [68], pens [72], plotters [71], and even flavours [44]). This project leverages the potential of digital fabrication to import sensor data as a variable in our patterns, creating designs that can be surprising [2, 27]. The unique part of this current project was the goal of using knitting to visualize each individual's heart rate in the design of a shrug (a soft, cosy, and warm object). In previous research, knitting machines have been used to visualize a variety of data sources varying from news [46], financial [45], library [30], and satellite data [53] in soft tangible ways. Knitting in general can help tangibilize and record time [40, 52, 55–57], and craft techniques such as Quipu knots [66] and beading [63] can be used to tangibilize personal data. Knitting can also be personalized by individual crafters [22, 48], and adding sensors to crafting tools can make individuals more aware of and reflect on their embodied crafting processes [51]. In this project we highlight the ways that we collaborate with our tools [54]. Though we use digital fabrication, the resulting shrugs also show the manual craft of the second author with hand-crafted knots and stitching.

### Contribution

In this project we explore how individuals feel about having their heart rate data translated into a soft, wearable object. To do so, we captured moments during the pandemic as biodata portraits and fabricated that data into a soft wearable shrug for each participant (N=20) using digital design and a hacked knitting machine. We present the fabrication process and discuss insights from two studio workshops and follow-up interviews (N=10) on how people felt about seeing their data and the data of others, reflecting on the wearability of their heart rates.

## METHODOLOGY & IMPLEMENTATION

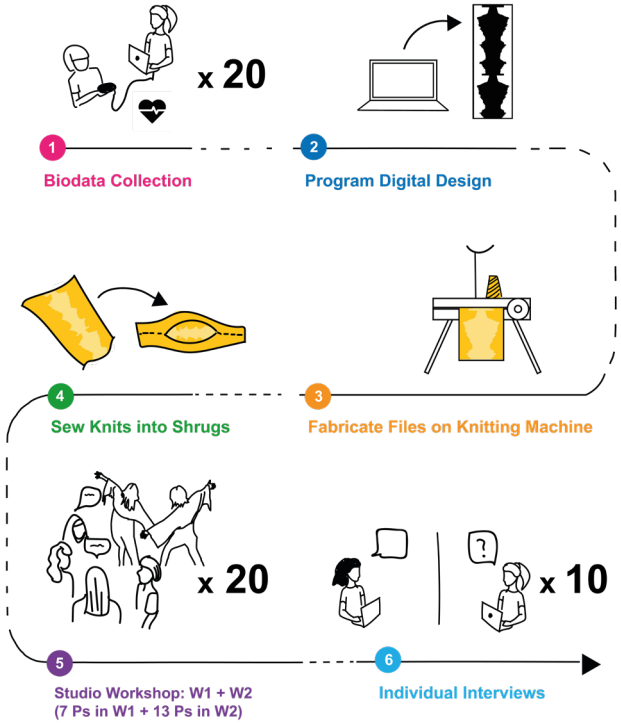
Twenty individuals participated in the 'Wear Your Heart on Your Sleeve' project. We discuss the process of data collection and fabrication of machine-knitted shrugs that aesthetically visualize their heart rate.

### Research through Design

For this project, we used Research through Design (RtD), a way of "exploring and speculating" [23] through design artefacts. RtD helps HCI leverage approaches from the humanities for exploring "third-wave" problems [7] where computing is "reaching out" [26] of areas with productive focuses and into more social and pleasurable areas of our lives. RtD can help with "under-constrained" [76] or wicked problems [12], or where there are conflicting trends [77]. In our case RtD is a way of making things that resist current usage trends of biodata for purposes of productivity, and to explore a "preferred state" [76] where biodata can be used to create objects that are cozy, soft, and warm. RtD is also suitable for our interdisciplinary project, which is situated at the nexus of visual art and design [21].

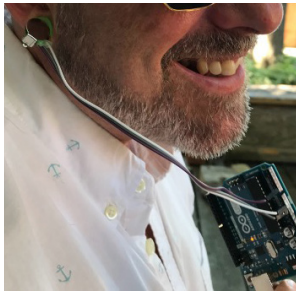
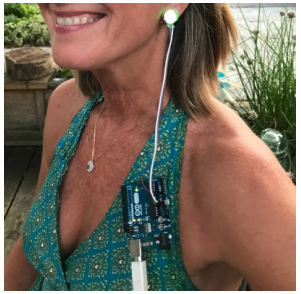
This project was about documenting the process (from heart rate gathering to the exhibition of the shrugs) for participants [5]. As an RtD project, we were interested in what we could learn from the process, as well as the making process in itself as an artwork that would be embedded in the resulting objects [6]. We also leverage the annotated portfolio [8, 37] approach of RtD, not in the sense of comparing several projects, but in that each individual shrug can be compared to the group of shrugs, and were presented to participants together as a collection. Our participants were able to explore and make sense of their individual shrug by seeing the designs of others, and we were interested in the insights that would arise from this comparison.

For this project we used each participant's heart-rate sensor data to control the aesthetic variables of the wearable design to create a type of bio-data portrait capturing that moment. We used a hacked Brother knitting machine [1, 15, 64] to visualize heart-rate sensor data in an abstract and aesthetic way. After knitting all the shrugs, we conducted 2 studio workshops where they could try on the shrugs, talk with other participants, and also explore the other shrugs. We later followed this hands-on experience with individual online interviews through Zoom with 10 of the participants [14].




### Heart Rate Gathering

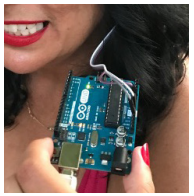
The first author created an Arduino program [3] with the heart rate pulse sensor [47] that would read an individual's heart rate and then export it as a text (.txt) file. The second author then met up individually with 20 participants (P1-P20) outside to gather their heart rate. During this data gathering session, individuals could try out the heart rate sensor in two locations (such as the ear lobe, or the finger), and could explore how different activities changed the output number such as physical activity (e.g. jumping), or trying to relax and lower their heart rate (e.g. sitting still).

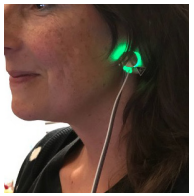
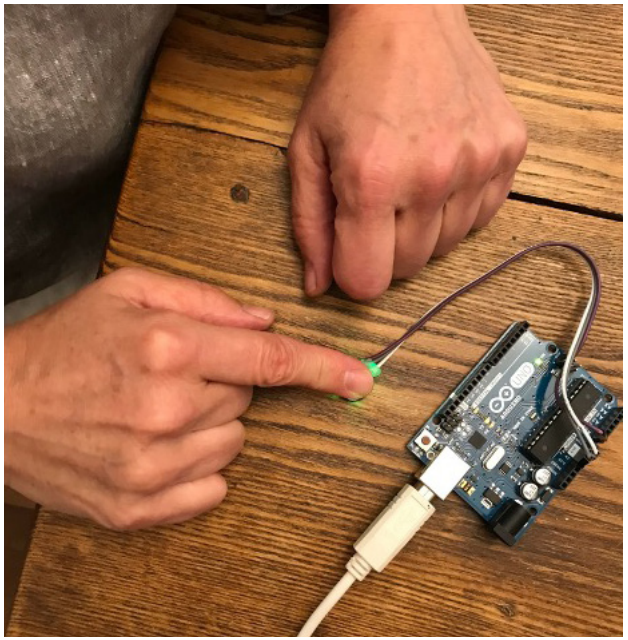







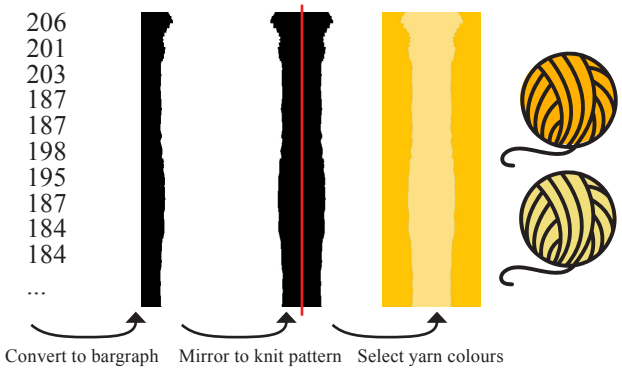




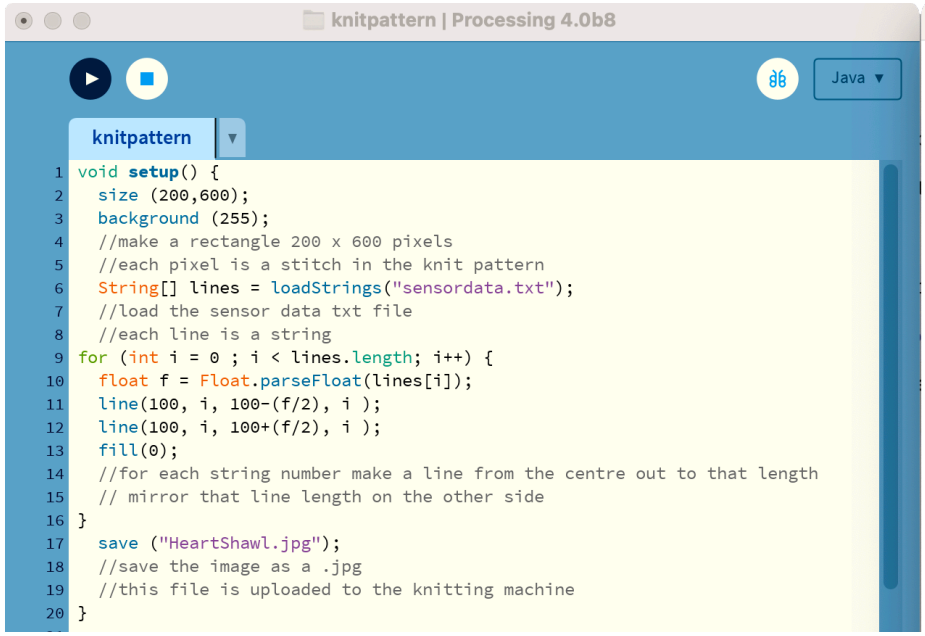
### Designing Knitting Pattern Files with Processing

Once we gathered the heart rate text files, the first author made a Processing program [20] that would transform the heart rate numbers into an image file for machine knitting. The Processing code would import the sensor data text file. With each number, the program created a black line to that length, and then mirrored and centred the design. The program would then export the design as an image file (.jpg), which can be uploaded to a hacked Brother knitting machine (Electroknit KH-950i) with img2track software [15].

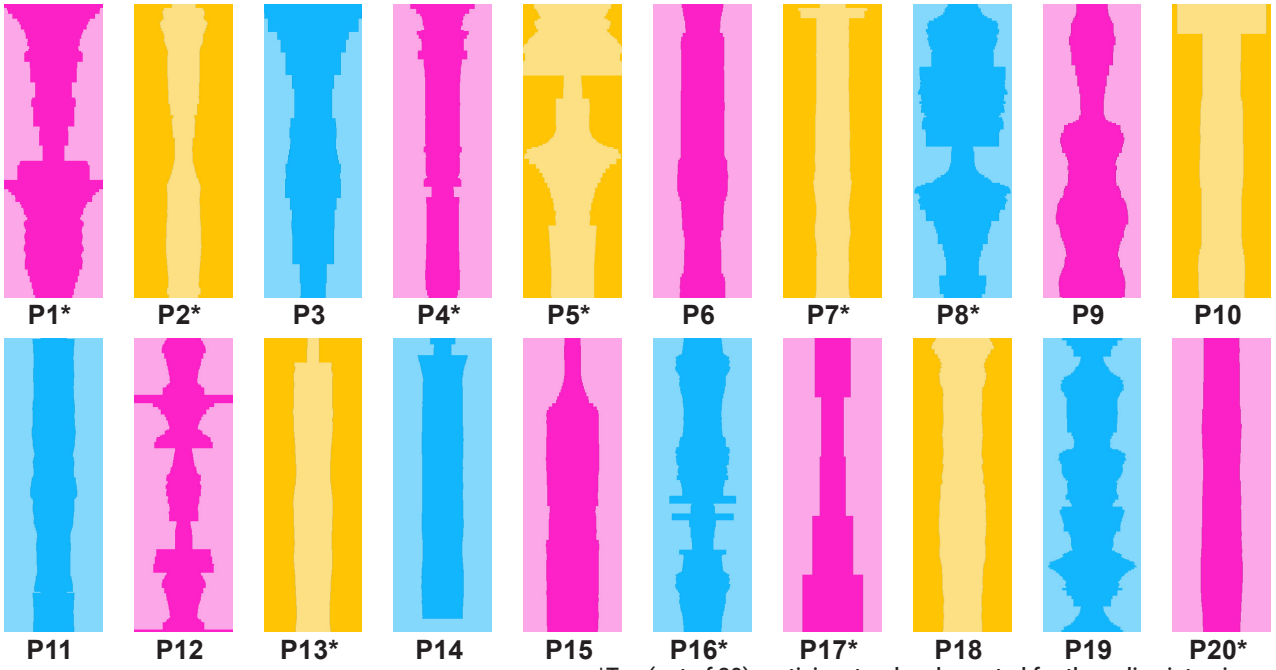



### Yarn Colour Selection

Before the design was knit, each participant was asked to select the yarn colour they would like to use for their shrug. We had three options including blues, pinks, and yellows. All of the yarns were made with merino wool.

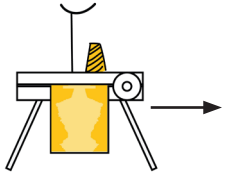






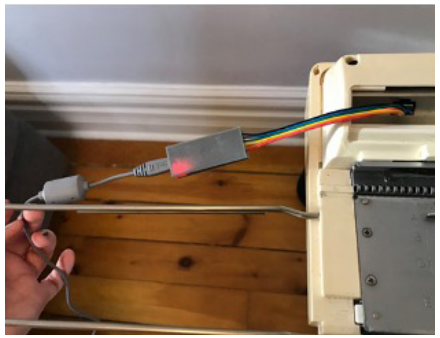

*Ten (out of 20) participants who also opted for the online interviews

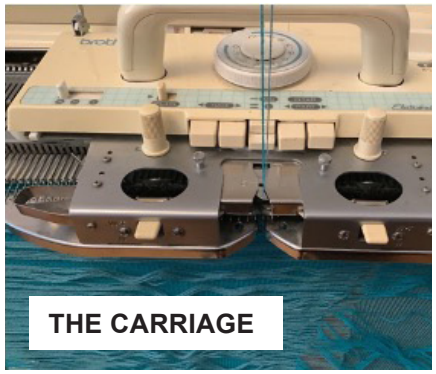
**Fabrication with Hacked Knitting Machine**



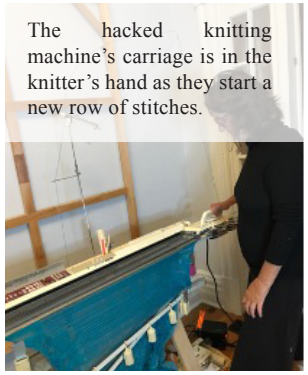
We hacked and used a Brother knitting machine (Electroknit KH-950i) with img2track software [15] to turn the 200x600 pixel image file created in Processing into a knitting pattern. Each pixel on the image is a stitch that the knitting machine creates, where img2track [15] tells the knitting machine to engage or not engage each needle. This transforms the black and white image file into stitches made with two different yarns.

Though the pattern process is automated with digital patterns and needle engagement, the process of moving the carriage (which hooks the yarn onto the needles or not) is manual. The knitter must also continually move up the weights to ensure that the machine creates a new row instead of stitching on previous rows.



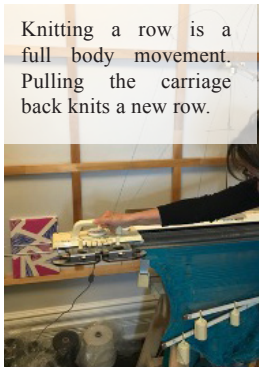


THE CARRIAGE



The hacked knitting machine's carriage is in the knitter's hand as they start a new row of stitches.

The carriage follows the pattern to change the yarn between the lighter and darker blue.



Knitting a row is a full body movement. Pulling the carriage back knits a new row.

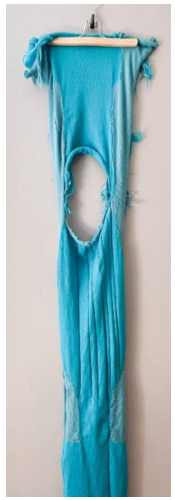
P1

P2

P4

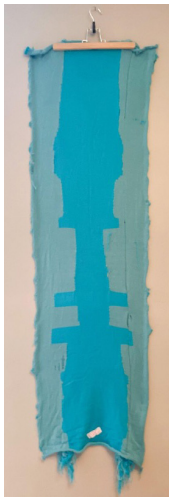
P5

P7



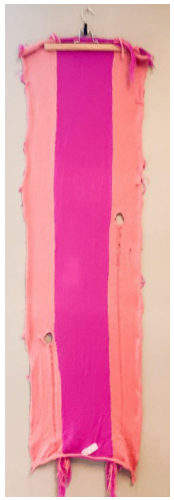
P8

P13



P16

P17

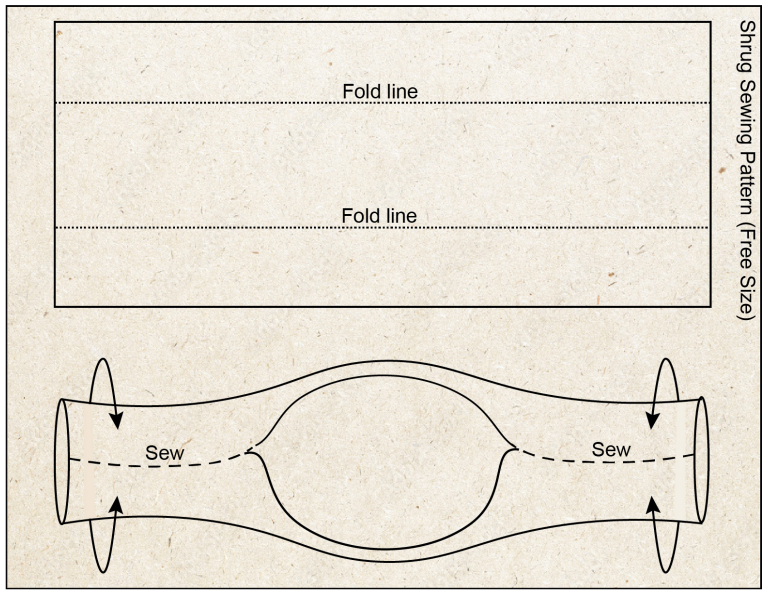


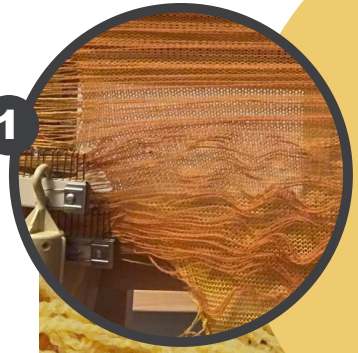
P20

### Knotting and Sewing the Textiles into Wearable Shrugs

The knitting machine used for this project was a single flatbed machine. We used Fair Isle knitting, where unused yarns create "strands" that are dragged along on the backside of the textile. Due to our colour-block design, the strands were long, and to manage this, after taking the textile off the machine we manually cut and knotted these strands to create a fringe that would be hidden on the inside of the garment. These strands can be avoided in knitting with a colourwork technique called Intarsia, but would have been more manually intensive during the knitting process on our machine, and from our perspective our "strands" were a limitation of our available tools.

Once these strands were cut and knotted, we had a rectangular textile that could be hand sewn (based on the sewing pattern below) to create wearable shrugs that each participant could experience as a garment that can be donned and doffed.



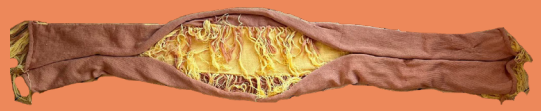
1 Machine-knitting that uses 'Fair Isle knitting' creates strands of yarn on the back when a yarn colour is not in use.

2 We cut and knot the strands together.

This creates a 'fringe' on the back side.

3 Once the knots are completed we have a rectangular textile that can be sewn into a shrug.

4 We stitch together the edges to make seams that create the sleeves of the shrug.



5 The shrug then becomes a wearable garment.

### Studio Workshops

Two years after the project started, and when it was safe to do so, we conducted two studio workshops inviting participants from the art project to meet up, have their photo taken with their shrug, and to meet and discuss the project with other participants. We conducted the workshops at two local arts organizations and had drop-in hours throughout the afternoon. When individuals arrived, we had a slideshow presentation explaining the process and showing how their data was transformed into the knit shrug. Each slide had the photo of the participant having their heart rate read, then their sensor data as the text file, followed by the produced image file for machine knitting, before the final knit result. All participants were able to join at least one of the two studio workshops and explore the other shrugs on the clothing rack and see other participants wearing theirs.

### Follow-up Interviews

After the studio workshops, we invited all participants to individual follow-up Zoom interviews [14]. Ten participants signed up to participate in the semi-structured interview. Each interview took approximately 30-45 minutes where individuals were asked questions including their experience of the data gathering session (to describe what happened, how it felt to wear the sensor, how they felt seeing their data on the computer), and their experience of the studio workshops (any expectations they had beforehand, their impressions on the knitted result, what it was like to see their data this way, and what they plan on doing with the shrug once it's delivered).

### Data Analysis

Data analysis began with the first author editing the automatic (verbatim) Zoom transcriptions [14] to ensure they matched the audio recordings. The first author then performed inductive thematic analysis as described by Braun et al. [9–11]. This involved importing the transcripts into MaxQDA [25] for analysis, a software that enables iteration of codes and themes for qualitative research through tagging and colour-coding. This included familiarization with the data, and then an initial coding of the complete dataset with codes that reflected the language and ideas our participants discussed. This initial list of codes was then grouped into central concepts to create narrative themes. Throughout the analysis, codes are exemplified with transcript quotes from participants.

# FINDINGS

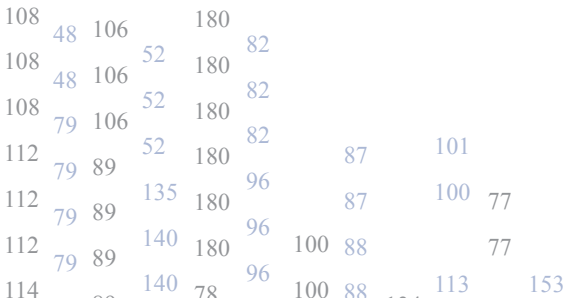
## Theme 1: DIGITS DON'T MEAN ANYTHING

### 1.1 Didn't understand sensor data

Our participants expressed that while looking at the numerical serial sensor output during the data-gathering session they saw "*a lot of activity on the computer screen [but] didn't really know what [they] were seeing*" (P20). Our participants described the raw data, "*whatever that meant*" (P1), as dry and lacking meaning. P5 summarized the experience: "*I didn't know what was going on with the numbers on screen. I wasn't really sure what the numbers meant. I could see them going up and down but I didn't know exactly what I was looking at*" (P5). P17 felt similarly while watching the sensor data serial out: it was all "*blah blah blah blah! I have no idea what the numbers mean*" (P17). In contrast, by transforming the raw numbers into a textile pattern, individuals could "*see it translated physically as the art piece. It went from something abstract to something very concrete and tangible*" (P16).

### 1.2 Less self-conscious of biodata

In contrast to previous work, our participants were not protective or attached to their data as raw numbers. As P17 summarized "*I don't have much of an attachment to it since it's just a number, but I found it very interesting that it was interpreted into a piece of clothing. I really dig that*". P7 echoed this statement, "*I feel like it's something I'm happy to share*." On its own, P4 felt that heart rate was data that couldn't be used against them, "*I don't see it as a personal kind of infringement in any way, like I don't see it as being data that could be used for malicious purposes*". Individuals felt less self-conscious about bio data being recorded and less of a requirement to be prepared and be "*presentable*". As P1 stated: "*[It was] better for me. I don't like to have my voice recorded, I hate seeing myself on video. So it's nice to have a recording that is like directly related to your biology*".




## Theme 2: PERCEIVING THE HAND-CRAFT

### 2.1 Manual collaboration with machine

Although the sensor data was imported into a computer program to create the knit pattern, our participants enjoyed seeing the aspects of hand craft and imperfection in the shrugs. All but one of our participants had no previous experience with machine knitting, and were surprised by the amount of physical effort involved where the carriage had to be manually moved back and forth to stitch each row: "*I realized that Greta Grip was so physically involved in doing the work*" (P20).

To our surprise, our participants liked the seams where the different colours joined creating a fringe. In manufacturing, these edges are usually stitched in or are only visible on "*the wrong side of the knitted garment*" (P17). In contrast our participants were drawn to these **loose ends**: "*I was really attracted to all the strings. I know that the artwork is the other side but for me it was all that residue on the other [side]. I was attracted to that part*" (P2). Participant 1 and 4 highlighted that they preferred the "*texture*" (P17) created by the fringe: "*At the place where the colours meet there were these fringes that were really interesting, so I wanted to turn it inside out*" (P17).

The result had more of the maker's hand, and this was more attractive than what our participants were initially expecting: "*I'm always interested in seeing the evidence of like, it's not that the pattern doesn't have the evidence, but the back is the evidence*" (P2).

### 2.2 Softer results

Overall, our participants were surprised by how the computerized knitting machine involved the manual hand of the maker, and more of a collaboration between the maker and the machine. As P20 summarizes: "*when I saw the final results, they're not at all what I imagined. I imagined something a bit more controlled or like machine made. They're more loose and fluid than I expected. It has developed into something actually far more interesting than what I was imagining*". They enjoyed seeing the errors or glitches in both the sensor data readings and in the translation to the knit pattern: "*That's craft right? It was really intriguing seeing how the data transferred and some of it skipped beats. I like the skipped sections*" (P2).

They expressed similar feelings about the way the sensor data was used in the pattern design, initially expecting it to be more like heart rate visualizations such as "*EKG*" lines or "*pulsation*" (P16). As P5 summarizes: "*I think I imagined it maybe looking kind of like a heart. I remember the EKG machines like that type of a visualization. So it was really cool to see just the shape of it and the colour, and how it came out*".

**"The back is the evidence" (P2)**

## Theme 3: PERSONALIZATION: INCREASED PRECIOUSNESS & DECREASED WEARABILITY

### 3.1 More personalized

During the studio workshop, many of the participants compared the different shrugs, and found it interesting to "*see the variety of patterns*" (P2). Participants felt that the shrugs suited each individual. Part of this was the ability to select their own colour, as P1 summarizes, "*It was nice to see each individual put it on and see how it really suited everybody, you know, because it's like you asked the question about the colour choice, and each person sort of made a choice of the colours.*"

This personalization was discussed as being in contrast with manufactured clothing and wearables: "*There's a unique quality for fashion that relates to mass production and mass consumerism. All these companies are producing items [and] they want to put you in this box, whereas these pieces are created dynamically, specifically, for that one individual. So, it* ***expresses*** *your personality in a way that no other piece of clothing can*" (P17).

The customization made each participant feel that their own shrug was uniquely theirs: "*I love seeing this unique fabric for every person*" (P17). Each shrug was "*very different from person to person. Some of them were totally straight others had lots of like waves and lines in them*" (P5). P4 found the shapes "*interesting because of the variety that you were able to get from those numbers*". The patterns also led to curiosity about the other participants, and asking each other about what they were doing at the time of the data collection. The artifacts were described as *"a good conversation starter"* (P7). As P16 describes: "*So you're wondering what they were doing when it was recorded*". P13 also elaborated: "*people had different designs and then, when asked what they had done, saying they had done like slightly different things. It was interesting to see the differences*".

Beyond creating wearables for each unique person, the visualizations were also described as capturing a unique period: "*that was a moment in time that was recorded*" (P16). Our participants described the heartbeat as not only a biomarker but also being unique in compared to other biomarkers in terms of how it would change from moment to moment: "*It reminds me how we all have our own DNA, our own footprint, fingerprint, ear shape, and heartbeat, and our heat beats will change throughout the day, throughout the years, whatever is going on. So, no two will ever be the same*" (P17).

**"*It expresses your personality in a way that no other piece [..] can*" (P17)**

**"I chose the blue because it's a colour I love to wear" (P16)**

***"I'm really into pink... since the pandemic"* (P17)**

***"All my outfits are black, but I decided that... this year I would try to break out"* (P2)**

### 3.2 Colour-choice

Participants each had unique reasons for the colour of yarn they chose for their shrug. For example, one individual chose their colour based on the biofeedback sensor and made it a visual pun: "*It's kind of cheesy, but Neil Young 'heart of gold' [song name]*" (P5). The shrugs together highlighted the individuals preferences of each individual: "*There were so many individual elements that are involved in it. It's not only personal preferences across the board for colour selection [but] what kind of [palette] appealed to people or spoke to them in that moment, or that day, or your favourite colour, who knows?*" (P5)

Several highlighted the wearability of certain colours and discussed choosing their favourite colour to wear. Individuals also mentioned what colours look good on them – and are viewed as "*wearable*": "*My favourite colour is red, but I didn't choose pink, I didn't choose the yellow, I chose the blue because it's a colour I love to wear*" (P16). Others purposefully broke out of their traditional colours. "*All my outfits are black, but I decided that anything that I was going to get* ***this year I would try to break out*** *– so what's the brightest colour there is, yellow? I'll go with that*" (P2). P17 chose a colour that would reflect the changing period of their life: "*I'm really into pink, and pink [was] not my colour, and that's why I chose pink.* ***Since the pandemic*** *I've just been really attracted to these like bright colours. I don't know if it's my age, my hair colour changing, but I'm really attracted to these pinks*".

### 3.3 Preciousness

When asked about what they would do with the shrug once it is delivered, 5 of our 10 participants discussed wanting to hang it rather than wear it. Due to the construction of the shrug, where the knitted panel was not damaged during the sewing process, it could be turned back into a rectangular panel by taking out the seam thread. One motivation was self-expression instead of storage: "*I wasn't expecting to see this big beautiful piece of artwork in itself. The fact that we can put them on our bodies is really awesome, but I see them more as a hanging, something that I would put on my wall. I'm displaying it, I don't want it to hang in my closet. I want it out somewhere to be seen*" (P1). Other reasons included preservation and safety as wearing the item was viewed as putting it at risk for damage over time. "*At first I thought I wanted to wear it, but it feels so special. I would like to hang it. I think I would like to keep it safe*" (P16). Hanging it was discussed as facilitating more discussion on what it looked like and to describe the process. As P5 summarizes: "*I will probably display this as art rather than wear it. I think that it's really special and it would be really neat to be able to preserve it, and to be able to tell that story and experience with people that come to my house, and you know, talk to them and about what it is, and what it looks like.*"

## Theme 4: OPPORTUNITIES FOR ITERATIVE CO-DESIGN

Due to the limitations of the pandemic and the timeline of the project, the steps of the pattern-making process were linear and staggered (i.e. there were separate steps for data gathering, creating the Processing program, and then pattern design creation). Our participants expressed wanting to experiment more with how different activities would influence the design, and in this way enabling them to co-author the knitting pattern designs in real-time and iterate on the design before it was stitched on the machine.

Once the data was gathered participants were "*curious what it [was] gonna turn into*" (P7) and "*excited to see how it would be used in a new way*" (P5). In contrast, in the current process, once the data was gathered it went into a black box in that it came out the other side completed. This led to participants feeling less artistic control over the process, and was a missed opportunity on our part for making the pattern design process less opaque. As P3 described her impression of the process: "*As soon as something gets mechanical. I'm kind of like [hands up gesture]. That's why you're doing it and not me, you know. That's why you're the artist and I'm not. Taking those numbers and then translating them into something algorithmic*".

### 4.1 Desiring dramatic design

Participants who had less variable heart rates throughout the session ended up with relatively straight lines in the knit pattern. Three participants with less variable designs expressed wanting to iterate on them more. P17 discussed the design on their shrug: "*It didn't look very dynamic or interesting [...] there wasn't any great change in line or shape*". P13 felt similarly: "*I was kind of upset at how boring my heart rate was!*" This was especially true during the studio workshop when they got a chance to see the 20 knit designs: "*It showed such a range where I thought, oh my god, my heart rate is like so static compared to people who had [...] these architectural kind of structures*" (P20). These quotes suggest that individuals would like to produce more variable and interesting designs in their knit patterns. P8 even suggested other patterns, "*It makes me think, how else can you generate those patterns? [...] I like twirls and circles. I think that would be cool.*"

### 4.2 Experimenting with different activities

During the studio workshop individuals discussed what they did during the heart rate gathering session. For example, some tried to remain relaxed and to calm their heart rate, whereas others experimented with different types of physical activity. For example, P5, "*stood up and down a couple of times, moved around, talked really loudly, talked really quietly, to see how you know whether or not my actions might influence the data that was being collected. It was a fun thing to kind of experiment*". P16 experimented with their breath: "*I was just fluctuating, talking differently or breathing differently, to see how it would react*".

After discussing the types of activities they tried, participants were inspired and wanted to try new things. As P20 summarizes: "*I heard other people comment about how they got up and did jumping jacks, and I just sat perfectly still. I didn't really have a sense that I should do something. I thought, maybe she needs me to be still for this, so that's what I did and consequently I have a very straight heart rate*". P2 felt similarly that they wanted to experiment further – "*I want to, now that I know!*". P2 also expressed curiosity about how different moods or emotional states would impact the design such as investigating different feelings or "*a broken heart*".

These comments highlight the opportunity that digital pattern designs provide for iteration. For example, with the Processing code already prepared, we could do further workshops where individuals iterate between data gathering and visualizing the knit design in real-time. This would enable individuals to experiment with the impact of different behaviours and actions on the crafted result, and they could potentially feel more ownership over what was produced.

## KNITTING THE DISCUSSION

### Seeing the craft in data physicalizations and personal fabrication

Digital fabrication, which is the ability to create digital patterns and files to produce physical objects [24], is increasingly enabling researchers to create data physicalizations [31, 36]. These objects *"whose geometry or material properties encode data"* [36] can be made with materials typically reserved for handcrafts, such as clay [16] and textiles [30]. Our findings align with previous work, which has demonstrated the ways that people enjoy seeing the "hand" of the maker [39], as well as the ways that even digital fabrication machines can create imperfections due to the added natural forces that they must contend with, such as gravity [4, 36, 62]. Our participants expressed an attachment to these glitches, hand-stitched seams, and fringes, which also might suggest an opportunity for more 3D textured designs rather than graphical colour changes in future work.

### Wearables and temporality

One of the greatest benefits of personal fabrication is the ability to customize and personalize items for oneself, which has unique advantages for wearable items which often have the goals of "perfect fit" and supporting self-expression [50]. In previous work with 3D printing wearable heart rate necklaces, participants responded positively to this customization and personalization [41–43]. As a result, we were surprised by the ways our participants expressed that personalization and customization made them want to preserve the knitted visualization rather than wear them as shrugs, and how wearable textiles were perceived as being "at risk". Many of our participants said that once they are given the shrugs to keep they will hang them as artworks to remember the period of time and to share the story of creating them. Our findings suggest that items that are precious might be incompatible with being worn or might be perceived by users as too risky to wear.

### Encouraging collaboration and iteration with biodata

We see 'Wear Your Heart on Your Sleeve' in the tradition of previous work that uses heart rate as a variable to control artistic outputs [68, 72, 72]. Our work also differed from previous examples in that we gathered the sensor data, went away to create the shrugs, and met up with participants once they were completed to show them the final result. In contrast, works like Metaphone [68], Heart Calligraphy [72], and HeartPlotter [71] all visualized and physicalized the artistic outputs in real-time. With Metaphone, participants held a heart rate sensor and watched as a circular machine dropped varying amounts of paint in different colours based on their heart rate and Galvanic Skin Response [68]. Heart Calligraphy [72] and HeartPlotter [71] both map heart rate to variables for a pen-plotter design, such as varying the length of the pen strokes on paper. Based on our findings, the benefit of these approaches is the ability for participants to experiment and play with how their biofeedback impacts the system. They can watch how their thoughts, actions, and behaviours impact the designs in real time. With our fabrication process, we were limited by the amount of time it takes to knit a shrug, and the manual effort involved, but researchers are increasingly able to incorporate live data into textile fabrication processes [2, 40]. The unique advantage of knitting is that, due to the use of continuous threads, the machine-knitted visualizations could be unraveled and iterated on multiple times. In future work, we plan to explore how participants can iterate and experiment with the Processing design for the knit patterns in real-time, and have a more active role in co-authoring their own biodata visualizations by choosing which ones get produced.

## CONCLUSION

'Wear Your Heart on Your Sleeve' was a Research through Design project that began during the pandemic, and within the pandemic constraints, as a way of documenting and remembering that strange time. The project involved meeting up with individuals outside to gather their heart rate data, and then turning that data into aesthetic wearable shrugs. Two years after starting the project we conducted two studio workshops with the 20 participants. We then conducted follow-up interviews with 10 of these participants on their experience of the data gathering sessions and their impression of the knitted result. We asked them questions about what it was like to see their own data, and the data of others in this way. Overall, we found that participants had difficulty making sense of numerical biodata, that they enjoyed seeing the hand-crafted aspects of the digitally fabricated knitted result, that personalization impacted perceived wearability, and future opportunities for enabling individuals to iterate and co-author their own designs.

### Limitations

Our participants contributed both their heart rate data and their choice of yarn colour. Our participants described the ways that these two design elements contributed to their feelings towards the uniqueness of their shrugs. As a result, we cannot isolate the impact of the data physicalization on its own, as their feelings towards the shrugs might also be influenced by colour.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