BodyPods: Designing Posture Sensing Chairs for Capturing and Sharing Implicit Interactions

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ABSTRACT

Today, it is not uncommon to find ourselves remote from those we care about. Despite the impact of mobile and social technologies on connectedness, recent studies suggest that it could be these very technologies that exacerbate a sense of loneliness. In attempt to help people feel more connected, we designed and created BodyPods, a remotely paired set of communicating chairs that facilitate a sense of presence by leveraging implicit actions such as sitting to communicate that someone you care about is home. Each BodyPod consists of a flexible surface with six pressure-sensitive and light-emitting pads that adjusts its shape to the body anatomy. As a person's body moves, limbs exert different pressure on each pad creating a live digital "bodyprint" that is mapped on the pads of other BodyPods through color and light. Findings from a 10 person user study suggest bodyprints may be distinctive, particularly among small groups of people with different body types.

Author Keywords

Furniture; Connectedness; Implicit Interaction; Ambient Display; Kinematic Transformation; Tangible Interface

ACM Classification Keywords

H.5.2 [User Interfaces]: Prototyping

INTRODUCTION

People create and leave behind implicit traces of their activities through their interactions with objects. For example, if John and Sarah live in the same apartment and John returns home after Sarah has left, he may infer that she spent time on the sofa based on the arrangement of cushions or even feel warmth if she was sitting there recently. Furniture provide particularly interesting tangible media from which to capture implicit interactions because people spend a significant portion of their day interacting with them. Capturing and sharing these implicit interactions could offer remote loved ones a similar sense of awareness that John and Sarah experience from living together and seeing traces of each other's activities.

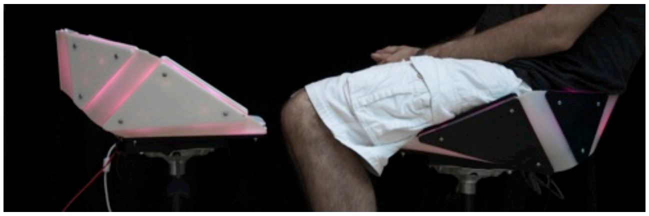

Figure 1. Each BodyPod senses the bodyprint of a person and maps it to its paired BodyPod through color and light.

Inspired by the notion of object-based implicit communication, we created BodyPods, a pair of remotely connected chairs that can sense the "bodyprints" of their users and share them as mappings on each other's surface (Figure 1). Analogous to a footprint, a bodyprint manifests in real time the sitting posture of a person as a distribution of the pressure that their body and limbs exert against the cushions of the seat. Each BodyPod consists of a flexible surface of six pressure-sensing and light-emitting pads. The surface adjusts its shape to the body anatomy, ensuring consistent contact with the sensing pads during different postures. When a person sits on one BodyPod, his/her bodyprint is reflected on the pads of the other BodyPod through color and light. Each BodyPod has a unique color ID. If two users sit on their BodyPods concurrently, their colors blend in each pad based on their relative pressures. If a user leaves, his/her bodyprint fades away with time. We selected chairs as the first type of a series of furniture due to their frequent and intimate relationship with the human body during daily activity: we sit during work, dining, leisure, and social interaction.

We conducted a formative study with ten participants with a range of body types to gather two types of data. The first type is a quantitative collection of bodyprints across five postures to evaluate differences between them. The second type is a qualitative feedback from participants on the concept of sharing implicit interactions with furniture for connectedness through a semi-structured interview after

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they had used BodyPods. Results from our visualizations of participants' bodyprints suggest that they are distinct for people of differing heights and weights. For connectedness scenarios where the number of people using a chair is limited, like family members, BodyPods may be able to uniquely identify the sitting person based on the bodyprint and allow the remote chair to display a unique color conveying visually who is using the chair. Likewise, BodyPods may be able to recognize specific body postures with interesting applications as embodied gestural interfaces.

PRIOR WORK

Object-based social connectedness is a well-established area in HCI and TEI, particularly for couples in long distance relationships. One common theme in past research is the explicit, deliberate character of interaction that augmented paired objects allow. For example, using *Cubble* [8] a person can author "tap patterns" to send to their partner. Similarly, pushing the semi-transparent button of the *FeelLight* [13] prototype changes the color of all the remotely connected buttons. In *LumiTouch* [1], squeezing one picture frame causes its remote twin frame to color-illuminate based on where, how hard, and how long the frame was squeezed. In *Casablanca* [7], researchers created a Lamp and Curtain through which people can explicitly share their availability for communication. In contrast to these explicit interactions we focus on implicit interactions people have with furniture in their daily lives. For example, LumiTouch frames also include motion sensors that detect ambient presence around their remote frame.

Another common theme in past research is the synchronous aspect of interaction. For example, the *Cubble* system also includes "mutual handshakes" where cubes heat up when remote partners simultaneously squeeze them. *ComTouch* augments voice communication using a vibrotactile device sleeve on a mobile phone [2]. *The Bed* prototype recreates remotely the experience of sleeping in the same bed by utilizing pillows that exchange heat and vibration and a swaying curtain that indicates breathing rate [4]. Tollmar et al. also explored the concept of virtually living together through user research and several prototypes [14]. Most closely related to our work, their SoftAir inflatable chair senses weight and movement and represents them on a remote chair through embedded lights and sounds allowing users to simultaneously interact. While BodyPods allow synchronous interaction, we are particularly interested in exploring their ability to connect people asynchronously by capturing, sharing, and playing back animated bodyprints. Often, couples live in different time zones making synchronous interactions unlikely.

A third common theme in past research and most related to our work is body posture recognition through pressure-sensing seats. Typically such directions focus on retrofitting the back and seat of existing seats with pressure sensing units with the objective of minimizing the number, location, cost, and computational complexity of input measurements [10,15,16]. For example, Mutlu et al. focused on the problem of optimizing number and locations of analog pressure sensors concluding to 31 units (they eventually used 19) with which they recognized 10 different postures [15]. Ashgar et al. used 8 binary pressure sensors (switches), a RFID reader, a digital compass, and a RFID grid for detecting 8 body postures, user identity, and chair's orientation and position respectively [16]. Mota built a static posture recognition system using two grids of 42x48 pressure sensing units distinguishing between 9 different postures [10]. In contrast to these works we are interested in how to design a seat to better sense postures rather than how to best place sensors on an existing chair. By rethinking the form of the seat we managed to use only six pressure sensing units for posture detection. Furthermore, we are interested in visually communicating postures among humans rather than computationally recognizing them. Also, in contrast to [16], we were motivated by the theory of affordances [17] to use pressure for user identification because it is a modality that we believe sitting affords better.

Our main contributions can be summarized as follows: (1) We present a novel kinematically deformable seat design that uses only six pressure sensitive units to capture body postures. (2) We introduce the concept of bodyprint as a means to visually communicate, synchronously or asynchronously, seated postures and potentially identify users. (3) We discuss findings from design, material and fabrication explorations for interactive and kinematically flexible seats that can be useful to designers and researchers in the field of TEI interested in augmented furniture. In the rest of this paper we discuss the motivation, design process, technology, and early tests of our work.

DESIGN AND PROTOTYPING PROCESS

Concept

During early conceptualization phase we considered both how connected seats could detect and exchange bodyprints and how connected tables could allow users to exchange tap signals by knocking on their surfaces. We proceeded with the former because of the richer tactile interaction and design exploration the direct contact with the human body allows.

Next, we considered the input/output modalities strategy. Instead of retrofitting an existing chair and dealing with problems of sensor placement and resolution, we decided to rethink the design of a seat as a kinematic mechanism that directs exerted pressure in predetermined sensor locations. Recognizing posture from a flat-surface sensor matrix is a non-trivial computational problem. By tailoring instead the geometry of the seat to closely follow the anatomy of the body we can place the sensors closer to the body parts that we want to use as input reference points. This way we can significantly reduce the number of required sensors and the computational complexity of dealing with input. To match

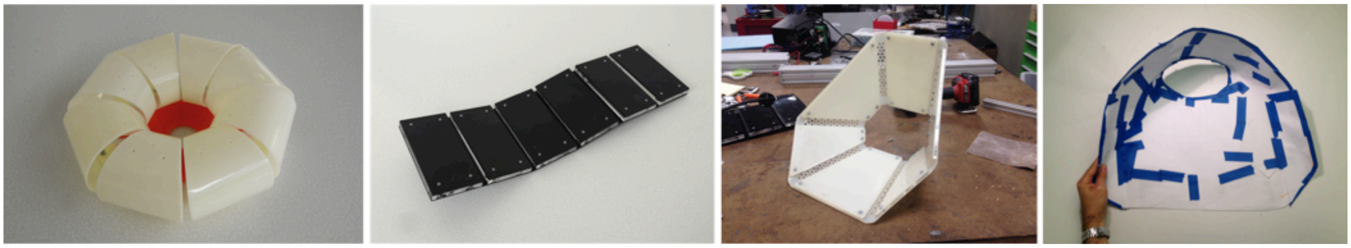

Figure 2. Form explorations (from left to right): donut-shaped form; lounge chair; rolled tessellated surface; tailored paper model.

the resolution of the sensors to the body anatomy we decided to place the sensors not inside the cushions as grids as prior works did [10,15,16], but instead under their rigid supporting surfaces turning effectively each cushion into large pressure sensor. We furthermore decided to color illuminate the cushion pads to visually express exerted pressure as a bodyprint.

Design Goals and Constraints

Our design constraints and decision tradeoffs were balanced between developing a technology to prove a concept and designing a seat ergonomically comfortable and sturdy enough for people to use it. On one hand, we wanted a prototype that could be easily reproduced in our lab for field experiments. This meant easy fabrication using standard equipment of a fab lab (e. g. laser cutting, CNC milling, 3D printing); easy manual assembly with minimum skills, effort, and time; easy transportation for deployment in homes for future experiments; and minimum waste of materials for affordable cost. On the other hand, we wanted a customizable design, tailor-made to the body types of different individuals: if the seat feels too large, the sensors will not provide consistent input; if instead the seat feels too small, the sensors' input will saturate. Furthermore, we wanted a seat that would be light-weight, flexible, and structurally efficient during deformations: if the seat is too flexible it will not support the body weight; if it is too rigid it will not follow the body anatomy during postures.

We initially explored two forms. The first was a donut-shaped form consisting of eight components made out of bent rolled sheets that would deform and spring back during sitting to cuddle the human body like a nest (Figure 2, left). Body posture could be inferred by sensing the pressure under each component, like an old-fashioned joystick. However, early prototypes showed that adjusting the flexibility of each part based on the thickness, radius, and geometry of the sheets was too difficult to control. The second approach was a lounge chair consisting of a flexible rectangular surface of six pressure-sensing and light-emitting pads (Figure 2, middle-left). This approach was easy to fabricate, however it did not provide enough contact points around the body to detect the variety of siting postures that we wanted. The chosen design direction was a combination of the two (Figure 2, middle-right). A rolled flexible surface consisting of six rigid pads: two triangular pads on each side and two quadrilateral pads for the bottom and back. The geometry is such that the side pads create hinges that spring back, allowing the seat to deform and fold, adjusting to multiple positions of the torso (Figure 3, right). Furthermore the form is structurally self-supporting: as the back pad leans, the side pads gently squeeze the torso preventing the back pad from leaning further (Figure 3, left). The benefits of this design are that it is lightweight, easy to assemble, has minimal volume, and consists of parts that can be laser-cut.

Fabrication Tools and Methods

We used CAD/CAM modeling and CNC fabrication methods due to the high level of customization of out parts, precision in assembly, and complexity of our geometric design requirements. We considered lasercutting and CNC milling in combination with planar flexible materials like plastic sheets and plywood as a rapid, low cost, and customizable fabrication technique. Our hardware lab is equipped with an Epilog 32"x18" laser cutter, which constrained the maximum size of our parts for the assembly. We also found 96"x48" CNC mills from subcontractors, however, their machining speed, cost, availability, and distance from our lab made this option unattractive. We therefore decided to use our laser cutter and modify our design assembly accordingly.

CAD Modeling and Parametric Customization

We used Rhino 3D and Grasshopper as CAD modeling tools. We wanted a parametrically customizable 3D model while guaranteeing that each of its instances consists of developable surfaces (e. g. single-curved surfaces like cylindrical or conic components) so that we could easily fabricate it by rolling/folding planar sheets. Furthermore we wanted to reduce the curvatures in few strategic locations to avoid jigs or complicated formwork during bending. Finally we wanted to ensure the geometry could fold during

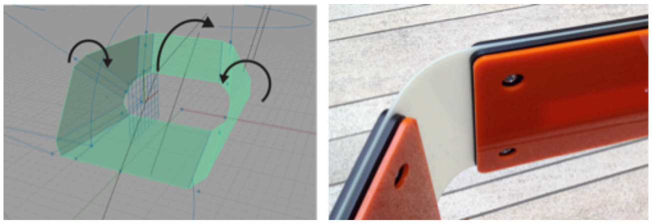

Figure 3. CAD parametric model for kinematic analysis (left); assembly detail of final Nylon/Delrin prototype (right).

Figure 4. Building the pressure sensing and lighting in the pads. From left to right: early prototype "bricks" to experiment with lighting behavior; wiring inside a pad; assembled pads; mounted pads with cushions on the Nylon chair form.

structural deformation without having its own rigid parts collide or intersect. To study the above constraints we developed a parametric model in Grasshopper, in which we customize length, width, slope, and a total of 11 parameters. The model (Figure 3, left), which was also used for kinematic and collision analysis, allows us to tailor-make customized seats for different body types reducing considerably the time for design iteration.

Materials and Forming

We explored a number of materials including plastics and wood based on their availability, cutting and molding ability, flexure properties and degree of translucency for lighting. Nylon sheets are practically unbreakable, flex back to their initial shape, can be thermoformed easily, and can be laser cut in thicknesses below 1/8" (e.g. 1/16" and 1/32"). Delrin sheets are also flexible and difficult to break (although less than Nylon) but they are springier and have better laser cutting quality than Nylon. Acrylic sheets cut nicely but are brittle. Polycarbonate sheets are flexible and unbreakable but they cannot be cut in the laser cutter. We also considered plywood, however it burns during laser cutting, it is structurally less efficient than Nylon or Delrin, and it requires expert skills and significant labor time for bending/forming (e.g. steaming, laminating, or scoring).

We tested a number of bending techniques including thermoforming, Kerfing or Dukta cutting patterns [5], and lamination. Thermoforming can be used in thermoplastics by locally heating the material with a heat gun or heat-bender and then manually bending it using a jig or a mold. Kerfing can be achieved by laser-cutting or CNC milling a surface to create spring-like perforated patterns. Kerf patterns decrease significantly the structural efficiency of the material while increasing the machining time, a significant cost consideration. After multiple tests, we decided to use 1/16" Nylon sheets for the flexible substrate, 1/8" Delrin for the panels, and ½" Acrylic for the translucent core to house the LED lighting and electronics. To bend the Nylon we used a heat gun together with small jigs and a heat-bender.

Early Prototypes

We crafted 10 prototypes in various scales (1/4, ½, full) exploring different forms, sizes, material properties, and lighting techniques. During early explorations we tailored a draft prototype by cutting and connecting paper patches with tape directly on a human body (Figure 2, right). The resulting prototype was used to determine proportions, dimensions, and helped us simplify the geometry during the CAD modeling process. We next developed few ¼ scale models using Nylon and Delrin to explore bending strategies as well as the degree of material flexibility. We also developed a full scale Delrin model to test bending techniques with the heat gun and structural deformation during sitting. Finally, we developed two full-scale prototypes from cardboard, one for finalizing the size, and a second for testing the electronic circuitry after optimizing the CAD geometric model.

Actuation and Circuitry

Early explorations included heating pads and mechanical actuation. Heating pads or Peltier tiles [11] could be combined with thermo-chromic paint to reveal or conceal shades of body prints. However, the time it takes for the thermo-chromic paint to change compared to how noticeable the effect is and the required power wattage and heat sinks for the thermal (Peltier) pads made this option unattractive. We considered mechanical actuation using a simple linear actuator to make the donut-shaped chair to contract/expand like a flower or the lounge chair to bend based on input from sensors. However the required electric current draw was too high and the resulting design felt too rigid. We decided to use color illumination in combination with pressure sensing. RGB LEDs can be programmed to associate unique color IDs to individuals. Figure 4 shows the initial bricks we built to test different lighting options, and how we built the pressure and lighting into the pads.

Electronic parts and circuitry was a challenging constraint, as they should withstand repetitive strain during bending while remaining functional. Our first approach was to avoid cables and instead embed the electric connections inside the Nylon using copper tape. When we tested this idea in a full-scale cardboard model we discovered that copper tape cracks under repetitive strain. Ideally we wanted to print the circuitry directly on the Nylon structural substrate with copper inkjet FLEX technology, turning the substrate into a large printed circuit board (PCB), however this was unfeasible due to time constraint and instead we used cables with connectors.

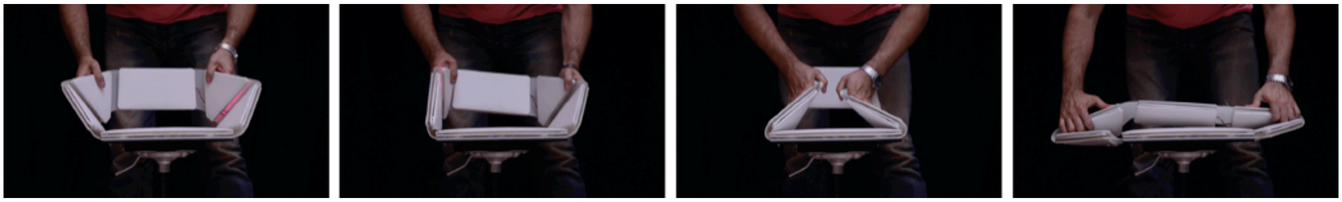

Figure 5. Each BodyPod consists of a flexible surface with six pressure-sensing and light-emitting pads that can deform and fold.

BODYPOD PROTOTYPES

The final prototype consists of a tessellated surface of six Delrin pads bolted on a flexible Nylon substrate. This combination allows the seat to easily deform under applied load (Figures 5 and 6). From outside to inside, the stacked assembly of each pad consists of: an external layer from Delrin; the flexible Nylon substrate that holds all 6 pads together; a translucent case made out of ½" sanded Acrylic that houses the LEDs and electronics; an layer from Delrin upon which the FSR sensor is mounted with a small cushion. These 4 layers are hold together with nuts and bolts (Figure 3, right). A fifth layer, the cushion pressure-sensing pad, consists of Delrin, foam, and upholstered Vinyl with hot glue. The cushion pad is structurally connected to the 4-layer stack with double-sided VHB tape allowing both relative movement and detachability. The FSR sensor is squeezed between the cushion pad and the 4-layer stack and is calibrated by adjusting the size, thickness, and rigidity of the VHB cushions. For the base of the seat we used a turnaround base from IKEA which comes on wheels. The FSRs connect to 10KΩ pull-up resistors. We used daisy-chained RGB Neopixels for the LED lighting (3 in each triangular pad and 4 in each quadrilateral pad). The electric connections inside each pad were instrumented by copper tape and soldered cables. Each pad has 4 pins (analog input from the FSR, digital output for the RGB Neopixels, 5V power, and ground), which connect through male-female cable connectors to an Arduino Micro, housed under the seat. After several iterations, we reduced the size and weight of the seat to the minimum that would allow us to prove our concept at an acceptable cost. For this reason, our final design is a hybrid between a stool and a chair providing a small back support for a person. We built two BodyPods, a white one and a black one (Figure 1).

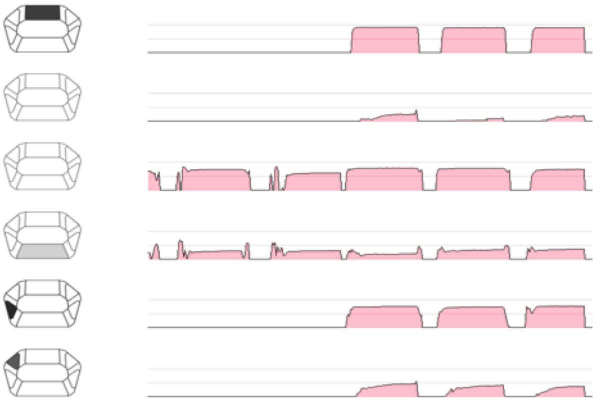

Figure 7. To help with development and testing we developed a time-series area graph of the pressure readings.

Remotely connecting the BodyPods

To remotely connect the BodyPods we integrated them with the Lab of Things (LoT) platform [9]. LoT is a flexible open platform for experimental research that uses connected devices in homes and beyond. The Arduino Micro in each chair communicates with a PC running the LoT Home Hub software over a serial connection which also powers the chair's sensors and lighting. Using the built-in data streaming capabilities of LoT, we wrote a LoT application that sends and receives data from the remote chair. With LoT integration, BodyPods can communicate with each other from anywhere in the world with network access, simplifying field study deployments and data collection.

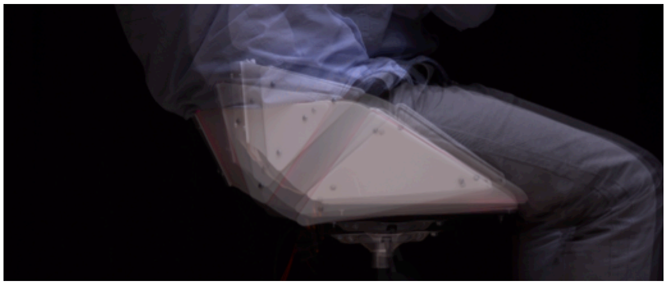

Figure 6. Kinematic adjustment of a BodyPod to body postures.

Visualizing Data Sensed by BodyPods

To visualize pressure data, we used Processing, an open-source Java-based programming language. We developed two visualizations: a time-series area graph of the exerted pressure on each of the six pads in real time (Figure 7) and an icon pressure graph that visualizes pressure as shades of grey for each pad (Figure 8). We used the second visualization as a real-time visual feedback to visualize bodyprints and to calibrate the sensors.

USER STUDY

To gather feedback on the BodyPods and explore how bodyprints differ across people and postures we conducted a formative user study with ten participants (5M, 5F). Each study session took about 30 minutes and participants received a $5 café coupon. We selected participants with different heights and weights to gather feedback from people with different physical characteristics. Participants came to our lab space where the two BodyPods were setup. We first explained the design motivation of sharing implicitly captured data to support connectedness and showed participants how the chairs illuminate based on data sensed either from their own sensors, the other chair, or the combination. We then gave participants time to sit in a BodyPod, use it and observe the behavior of the paired BodyPod. Our first set of semi-structured interview questions focused on connectedness, whether participants had remote people they would like to stay connected with, their reactions to furniture as a media for connectedness, or other ways they might like to interact with remote people.

In second half of the study, we gathered data to create bodyprints for five different sitting postures: Sit Straight, Lean Left, Lean Right, Lean Forward, Lean Backward. Participants sat in each posture for 10 seconds and repeated the posture three times. While BodyPods were particularly effective in capturing other postures such as Lean Back-Left or Lean Back-Right we did not include these postures in the study as they seemed rather unnatural. We concluded with another semi-structured interview session asking participants to comment on the possible design improvements for BodyPods, other input or output modalities that would be of interest to them and suggestions for other applications for the chair beyond supporting connectedness.

Bodyprints

We created bodyprints for each person based on their sensed data, shown in Figure 8. To create a person's representative bodyprint for a posture, we average sensor readings from the three repetitions of the posture. For each repetition, we manually identified the stable region of the ten second recording window (e. g. the middle 5 seconds) to ignore sensor noise as participants entered and exited the posture. Pressure sensors readings vary from 0 – 1023, after averaging we have six values in this range, one for each pad. To visualize the data, we map the pressure data to 0-255 and show the grayscale values for each pad in the Figure. The darker the image, the more pressure the participant was exerting against the pad.

Figure 8 illustrates the bodyprints of people in our study. The rows show the differences in bodyprints for participants in the same posture. People of similar weight have the most similar bodyprints. As weight and height vary, the bodyprints become more different. For example, when sitting straight (bottom row) pressure data is sensed only by the bottom pad for participants M2, M3, M5, F3, F4, F5, based on how they sit. However, heavier participants exert more pressure as we would expect. Bodyprints also capture differences in how participants sit straight. For example, M1 exerts pressure on all the pads and F1 sits with her back touching the backrest.

These images represent an initial analysis across stylized postures and ideal data collection conditions. Future analysis is necessary, particularly during naturalistic use, before we fully understand the uniqueness of bodyprints across people. However, these images suggest that particularly in a home setting with a relatively small number of people who may have different height and weights, BodyPods may be able to differentiate between people. This would allow assigning each person a unique color and provide the ability to send additional information to the paired chair about who was using the remote chair.

We were also interested in how bodyprints for the same participant would vary across different postures. The columns of Figure 8 show, as we would expect, that for the same person different postures have different bodyprints. This is most obvious for Lean Left and Lean Right, as force is exerted on the side the participant leans toward. However, differences in the other positions are also visible and we are interested in exploring whether someone observing the mapped bodyprints on the remote chair can identify different postures and whether such richness gives them more context about what activity the person in the remote chair might be doing (e. g. eating, reading a book).

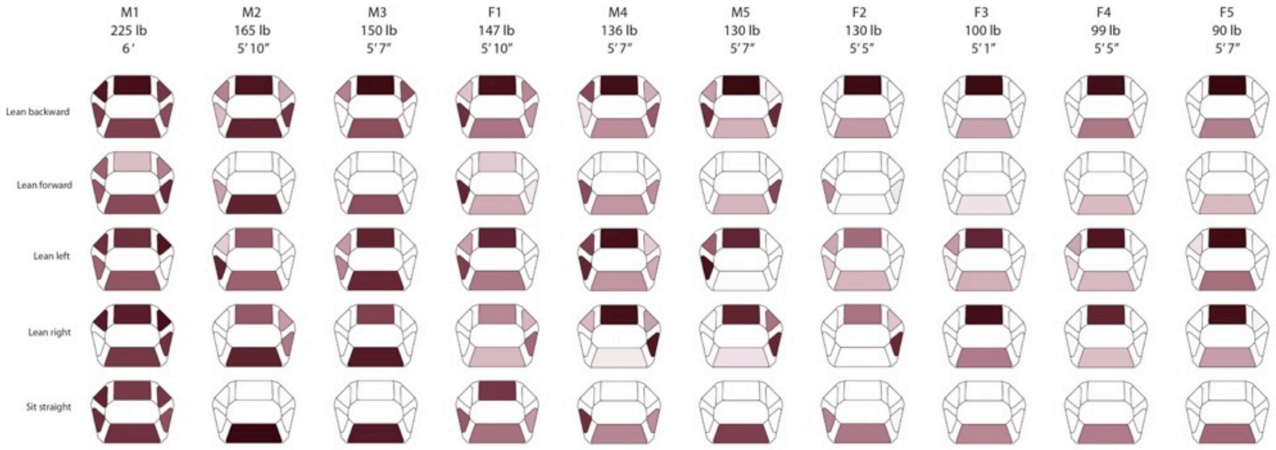

Figure 8. Participant's bodyprints for five postures. The darker the pad, the more pressure the participant exerted against it. To illustrate the pressure exerted, we mapped the average pressure values per pad ranging from 0 – 1023 to 0 - 256.

Qualitative Feedback

We elicited feedback through semi-structured interview questions from participants on the concept of sharing implicit data for connectedness, design improvements for BodyPod and possible applications beyond connectedness. Broadly speaking, the notion of staying connected with remote family or loved ones was attractive to 8 of the 10 participants. Each of these participants gave us examples of specific people they wanted to be more connected with. For example, several mentioned family in other countries. Three participants highlighted the value of asynchronous sharing, one mentioning that a 12 hour time difference between him and his parents makes synchronous interactions challenging.

Regarding BodyPods as a medium for connectedness participants highlighted aspects they felt worked well and places for improvement. Seven participants gave positive feedback about the use of ambient light to display pressure information. For example, M4 commented that ambient light worked well because it is not disruptive. However, four participants highlighted the inability to see color lighted displayed when they were sitting in the chair. As M1 said, "the chair is giving me feedback I can't see." Participants noted this was a problem for synchronous use of the chair. Hindsight suggests lights being placed closer to the edges of the chair or enabling them to show on the back exterior sides of the panels.

Participant feedback on the flexible nature of the chair was mixed. F5 and M1 commented positively about how the chair would squeeze them when they leaned back. F1 thought the flexibility made the chair more comfortable and playful and F2 called the flexibility "neat and different." On the other hand, four participants expressed concern about whether the chair would support them, particularly as they performed the leaning posture. For example, M5 commented that the lean felt unnatural and scary. F3 worried about breaking the chair and commented it was bending too much. Leaning concerns, particularly for leaning back, may be related to a feeling that the back part was too low, mentioned by six participants. M3, one of our larger participants, told us the back was too low and he felt he would destroy something if he leaned back. Another issue raised related to the low back pad was that it might lead to fatigue if people sat in the chair for a long time.

The time spent constructing a parameterized model that would allow BodyPods to be constructed in multiple sizes was validated by feedback of our participants about the size of the chairs. Two of our smaller participants (F3, M5) found the chair too large for them, while taller and heavier participants worried about breaking it. Building BodyPods in multiple sizes would be valuable.

Although we designed BodyPods for connectedness, we were interested in participant's thoughts about other applications. Seven participants mentioned sensing posture and alerting people to change their positions. F2 also highlighted that for people with some types of paralysis, a flexible pressure sensing chair that could be customize for specific body types could provide valuable feedback about how they sit, which they may be unable to feel. Other past research has found force-sensitive chairs can alert users for their posture in real-time to help prevent injuries [3]. Four participants suggested exploring applications in gaming and three were interested in security applications, for example if BodyPods could recognize a user and unlock a computer.

DISCUSSION

Our design and fabrication explorations as well as the user feedback suggest considerations for further research.

BodyPod Improvements

Results from user study encourage our initial decision to create a parametrically customizable production scheme for BodyPods. This can be combined with a better measuring system of user's anatomy such as 3D scanning. We also plan to increase the height of the back pad and use large-bed CNC routers instead of the smaller-size laser cutters. Furthermore, we observed that with one sensor, the bottom cushion pad had occasionally difficulties detecting near-edge sitting postures. This can be improved by either rearranging the sensor under the cushion pad or by introducing a second sensor (one in the front and one in the back edge of the seat). Other areas of future research include the development of learning algorithms for training BodyPods to recognize postures from bodyprint data.

Symmetry and Pairing of Connected Objects

We began our exploration of sharing implicit traces of interaction with a pair of identical chairs. We believe the symmetrical nature of the chairs and ability to use them both synchronously and asynchronously is appealing and has a clear mental model. Identical objects, e.g. picture frames, cubes, etc., have been commonly used in past connectedness research [e. g., 1, 2, 4, 13, 14]. However, there are other non-symmetrical options we think would be valuable to consider too. For example, having two versions of the chair in different scales, one in physical size for implicitly sensing input and one in miniature –doll house-size for displaying output. Having separate objects for local input and remote output could make it easier to support asynchronous interactions. The small chair could constantly be displaying a summary of the last several hours of data from the remote chair. This may be valuable for people trying to feel connected to others in different time zone.

Another area for exploration is whether connected objects are explicitly paired to only a single remote object or to multiple connected objects. Multiple connected chairs, perhaps each with their own color or set of unique colors per users, which share implicit data might be an interesting way to support connectedness across extended family members or close friends. We believe studies that help understand whether people prefer a 1-1 pairing for connected objects (e. g. this chair tells me about interactions with the one at my parents' house) or if an object can display implicit traces from many objects (e. g. this chair tells me about use of chairs at my parent's and sister's house) is a question for further research.

Beyond Connectedness

In addition to the aforementioned home connectedness scenarios we believe BodyPods may appeal for office use applications. For example, in their research studying chairs as input modalities, Probst et al. identified the use of tilting chair gestures as a valuable additional input modality for opportunistic, hands-free interactions in office settings [12]. The bodyprints created from user study data suggests BodyPods could recognize these types of tilting gestures. Probst et al. also experimented with bouncing gestures which may have a distinct signature in the pressure data collected by BodyPods, although we have not tested this.

CONCLUSION

DIY and Maker culture has, in the last few years, exploded across disciplines while promoting a new wave of non-verbal, tangible and embedded experiences that prefers the tactile over the virtual. We embraced the fabrication process to quickly generate multiple form factors and we tested their durability, functionality, and aesthetics. Additionally, microprocessors such as Arduino facilitated communication between objects therefore realizing this scenario. It is easier than ever to build and experiment with connected objects. Given the recent promise of Smart Home technologies and cloud connected experiences, it is plausible to assume that our furniture could become recipients, and broadcasters of our data. While this exploration started with chairs, we are curious to seek out other ways in which average household objects could implicitly connect us remotely. Telepresent technologies, and mobile communications may still serve as our primary mode of contact, but they require effort and time. A simple gesture, such as laying on a sofa and reading could suggest to another that you are home and resting. Perhaps that is all that is needed to feel closer across distances. We plan to continue to study the level of context that people wish to share with others as we further evolve the notion of connected pieces.

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BodyPods

Designing Posture Sensing Chairs for Capturing and Sharing Implicit Interactions

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People sharing the same space but having different time schedules often perceive each other's presence through the implicit traces their interactions with physical objects leave behind. If John, returning home after Sarah has left, feels the sofa warm, he may infer that Sarah was sitting there recently. What if we could allow remotely located people have the same emotional experience as John and Sarah have? BodyPods is a pair of multi sensory seats to emotionally connect remotely located people by sensing, exchanging, and visually expressing the "bodyprints" of their users as live gestural expressionss through the Internet. Analogous to a footprint, a bodyprint manifests a person's sitting posture as a distribution of the pressure that their body and limbs exert against the cushions of the seat. When a person sits on one BodyPod, his/her bodyprint is reflected on the pads of the other BodyPod through color and light. Findings from a 10 person user study suggest bodyprint signatures may be distinctive, particularly among small groups of people with different body types, allowing BodyPods to act as novel user recognition interfaces.

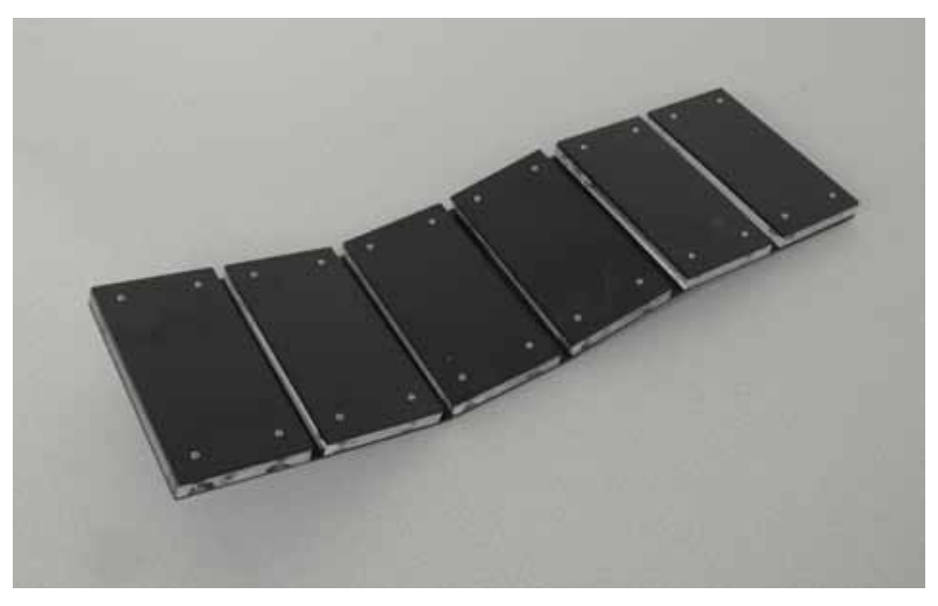
Object-based social connectedness is an established area in HCI and TEI with most prior works focusing on the explicit, synchronous, and deliberate interactions. In contrast, we are interested in the ability of objects to connect people asynchronously by capturing and sharing implicit traces of human activity that fade over time. We are also interested in the concept of a bodyprint as a digital signature of the person's identity and activity. Motivated by the Affordance Theory, we chose pressure because we believe it is a modality that the act of sitting affords better. Prior works on posture-sensing chairs focused on retrofitting existing designs with multiple sensors resulting in significant computational complexity with signal analysis. Our approach instead was to rethink the design and function of a seat in order to minimize the number of sensors and simplify their input analysis. BodyPods can detect eight postures using only six pressure sensors and a simple signal processing through a novel flexible shape that adjusts to body anatomy ensuring consistent contact with the sensors during posture transitions.

Contributions: [1] We present a novel kinematically deformable seat design that uses only six pressure sensitive units to capture body postures. [2] We introduce the concept of bodyprint as a means to visually communicate, synchronously or asynchronously, seated postures and potentially user identities. [3] We present findings from design, material and fabrication explorations that can be useful to designers and researchers in the field of TEI interested in augmented furniture.

DESIGN

We tailored the geometry of the seat to the anatomy of the body to place the sensors closer to the body parts that we wanted to use as reference points. This decreased the number of required sensors and simplified the computational complexity of their signal analysis. Early concepts include a torus and a rectangular surface with pressure-sensing elements. The final design combines the two: a flexible truncated conical surface consisting of pressure-sensing and light-emitting pads. The surface adjusts to the body anatomy ensuring consistent contact with the sensors during body movements. Furthermore the form is structurally self-supporting: as the back leans, the sides gently squeeze the torso preventing the back from leaning further. We developed a parametric CAD model in Rhino/Grasshopper which was used both for kinematic/collision analysis and for customizing seats to different body types.

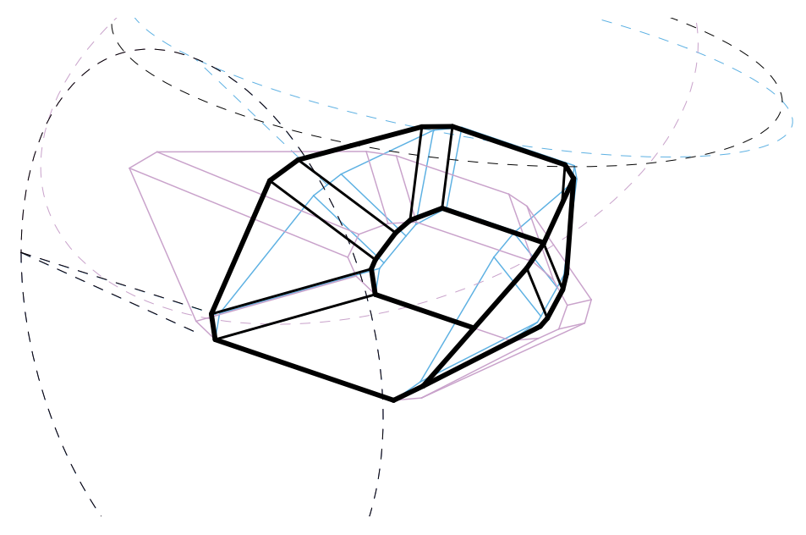
The torus (donut) concept concsists of 8 pressure-sensing and illuminating components



The lounge chair consists of a rectungular flexible surface with 6 interactive pads

Tailor-made prototype consisting of paper patches for determining the form and size.

The final concept, combination of the donut and the lounge chair

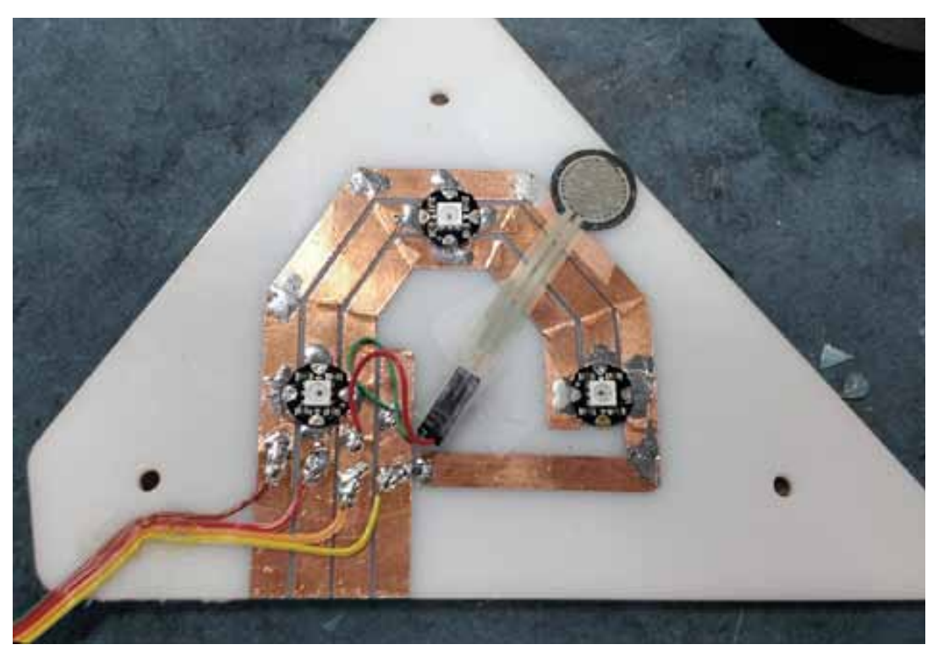


Parametric CAD model in Rhino/Grasshopper used for kinematic analysis, collision detection during folding and customization of dimensions.

HARDWARE

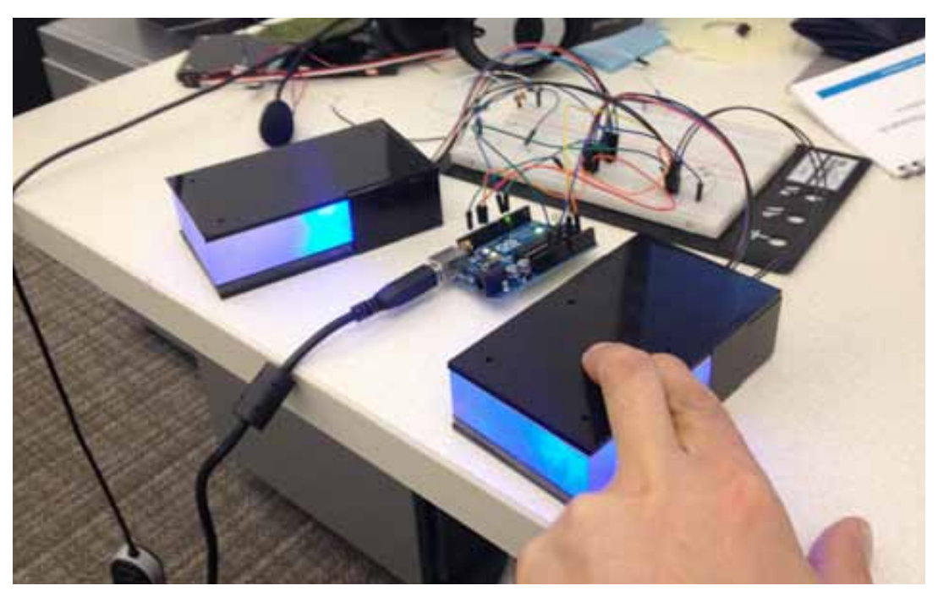
Each pad contains an FSR pressure sensor and an array of RGB LEDs. The 6 pads connect to an Arduino Micro under the seat's base which connects through a serial USB port to a computer that runs Microsoft's Home OS. The computers connect through the Lab of Things (LoT), a flexible open platform for connected devices in homes and beyond. Through the LoT, the sensors of each BodyPod's pads map to the LEDs of the corresponding pad of the paired BodyPod. To visualize pressure data, we used Processing, an open-source Java-based programming language. We developed two visualizations: a time-series area graph of the exerted pressure on each of the six pads in real time and an icon pressure graph that visualizes pressure as shades of grey for each pad.

The 6 pressure-sensing pads

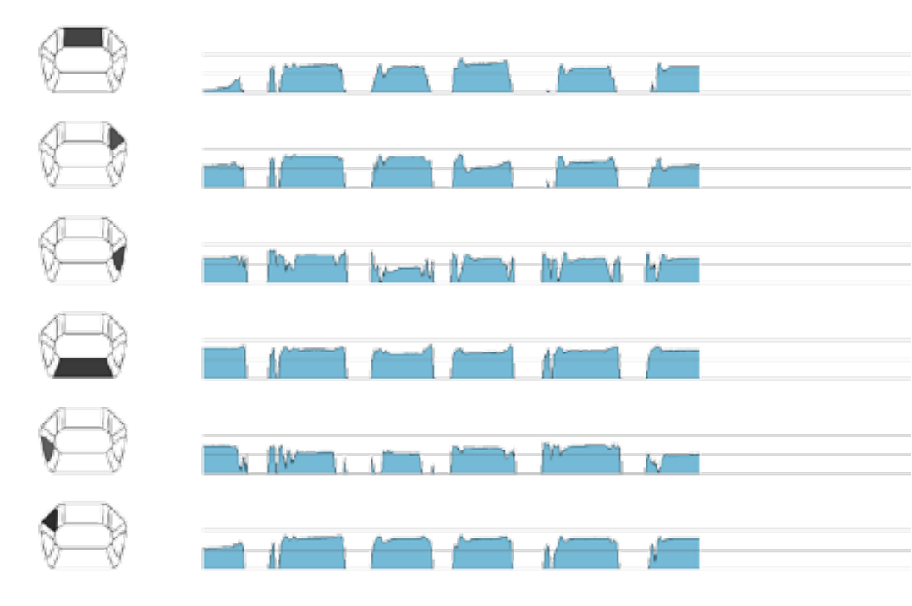


Each pad contains 3-4 RGB NeoPixel LEDs and an FSR sensor.

The six pads mounted on the flexible substrate during assembly of the prototype.



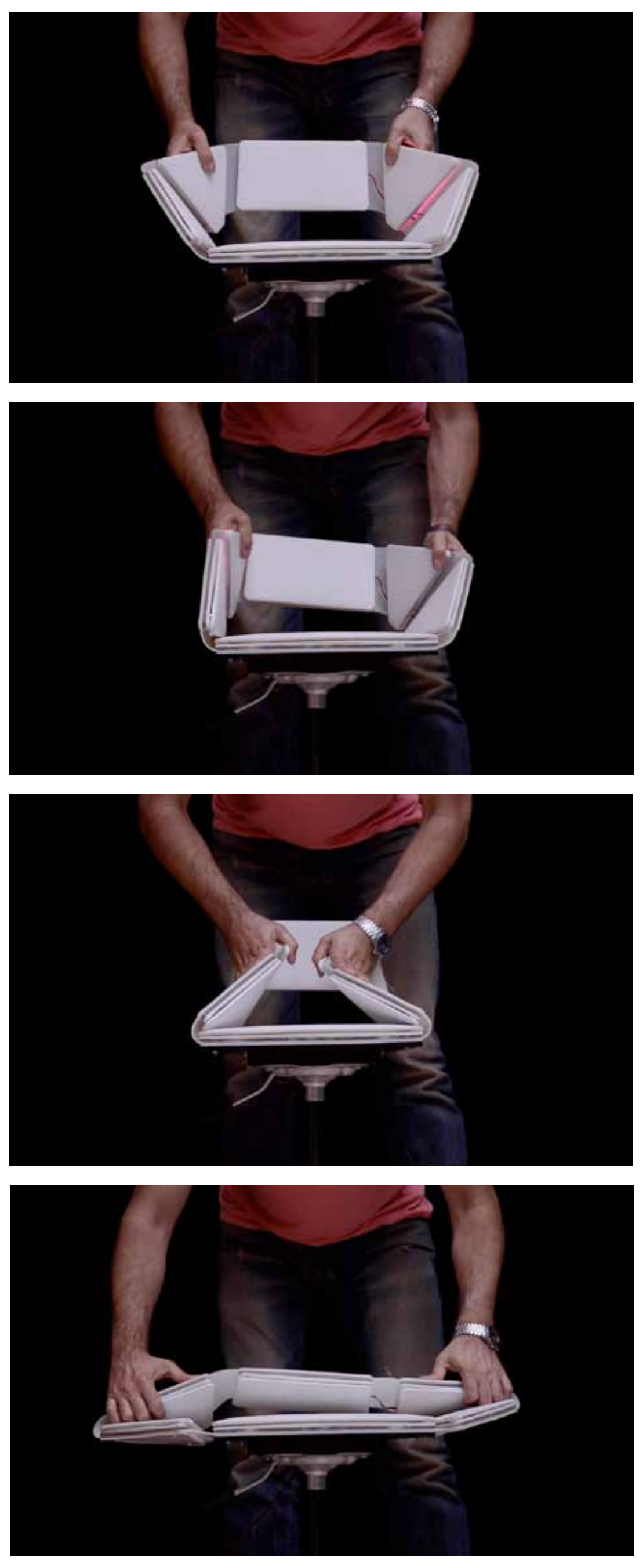
Prototypes testing interaction and communication between two pressure-sensing bricks.



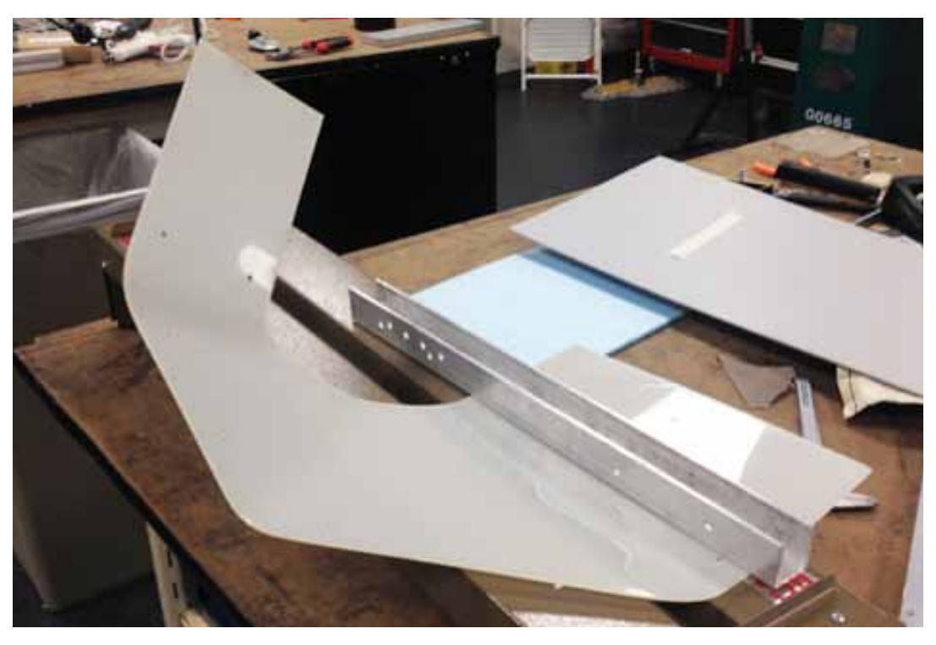
Sensor measurements from each of the six pads during user study.

MATERIALS

We used Nylon for the flexible substrate. The stacked assembly of each panel consists of (outside to inside): a layer of Delrin; the Nylon substrate; a translucent layer of acrylic that houses the electronics; and a layer of Delrin upon which the FSR sensor is mounted. The 4 layers are bolted together and a cushion pad consisting of Delrin, foam, and upholstered Vinyl, is mounted on them with double-sided VHB tape, allowing both relative movement and detachability. The sensor is compressed between the cushion pad and the 4-layer stack and is calibrated by adjusting the size, thickness, and rigidity of the VHB cushions. Thicknesses: 1/16" for Nylon, 1/8" for Delrin, and ½" for Acrylic. We formed Nylon with a heat-bender.



Each BodyPod consist of a flexible substrate with 6 rigid surfaces that springs back to its original form when no force is applied.

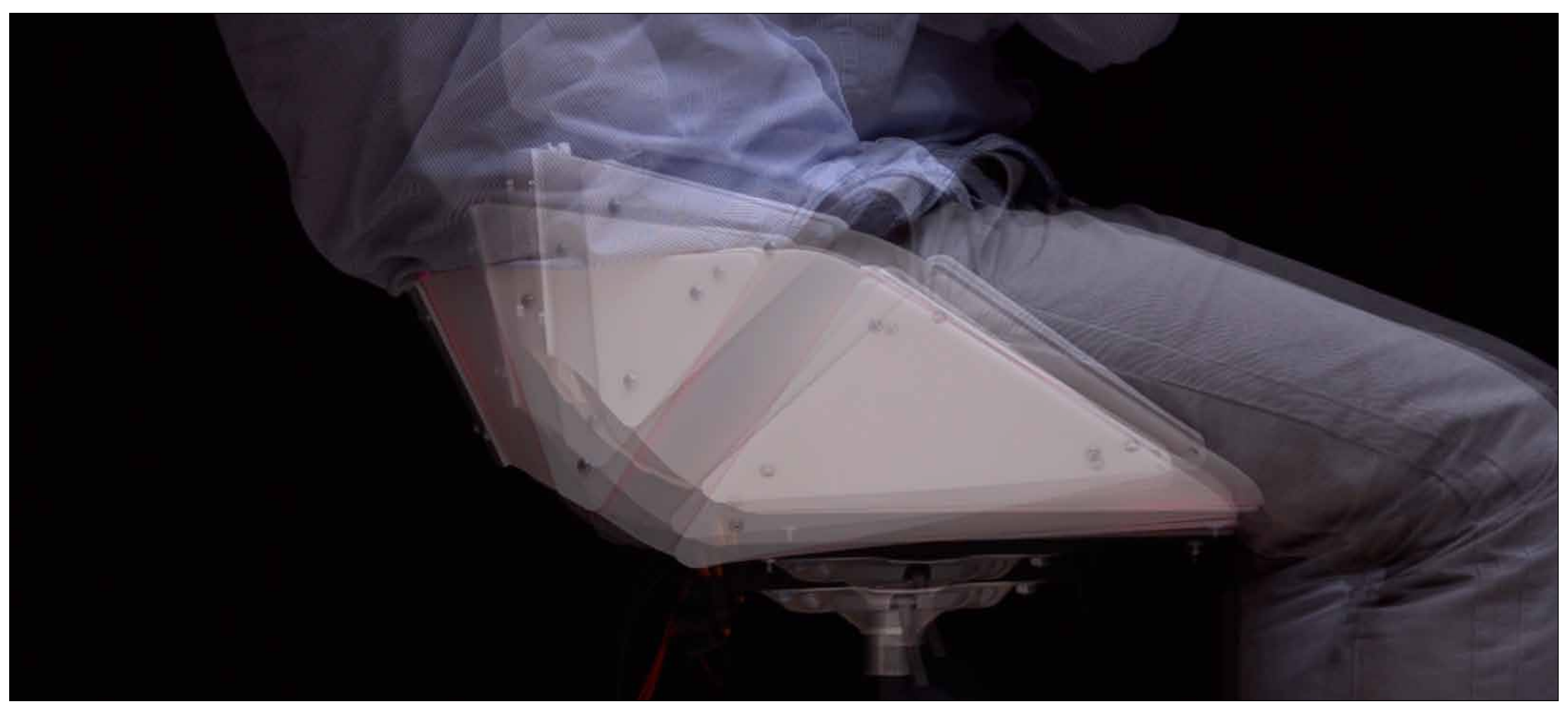


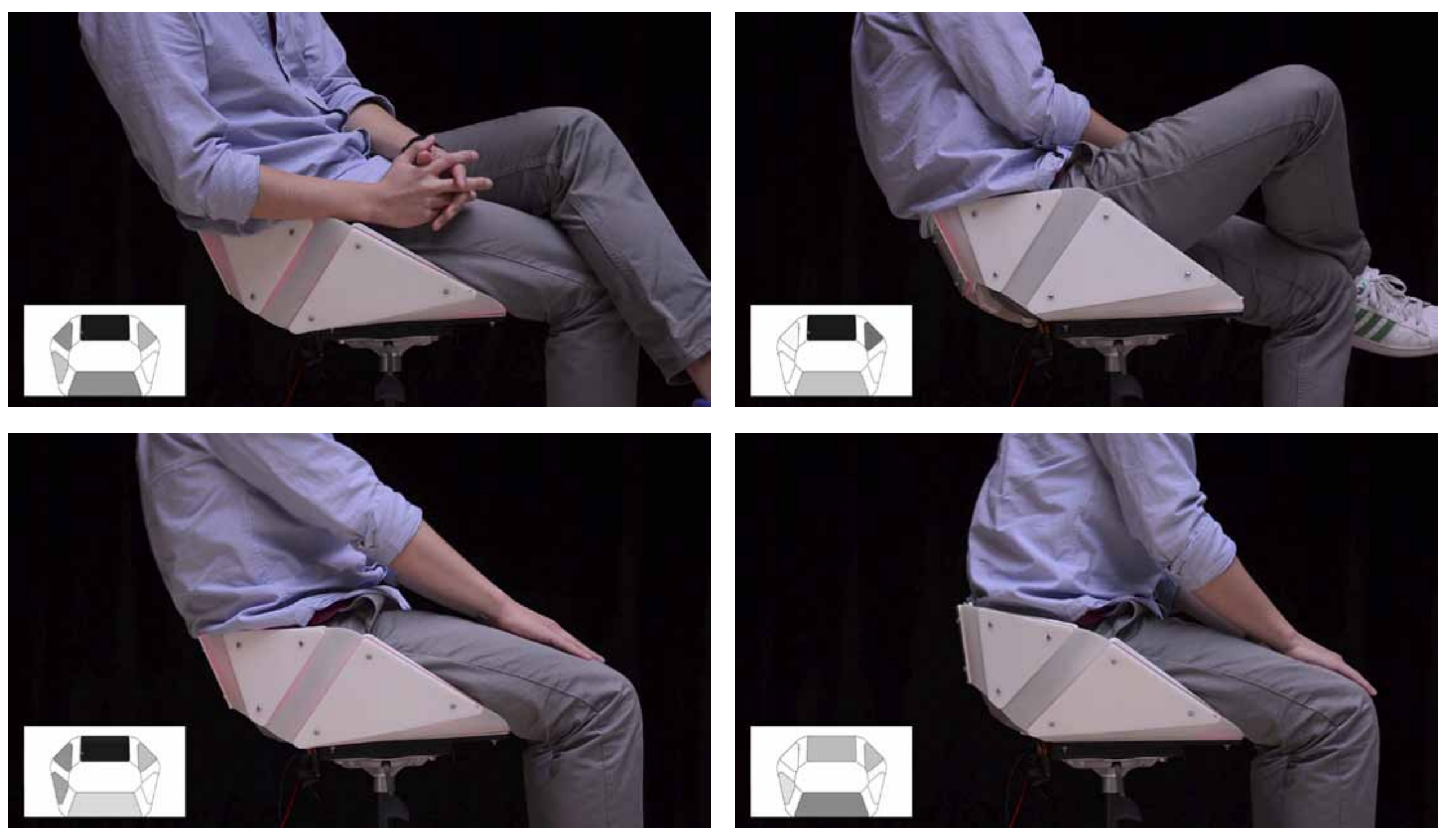
The Nylon flexible substrate was first cut in the laser cutter and then formed using a heat bender.

Detail of the assembly showing the flexible Nylon sheet and the rigid Delrin pads.

INTERACTION & RESULTS

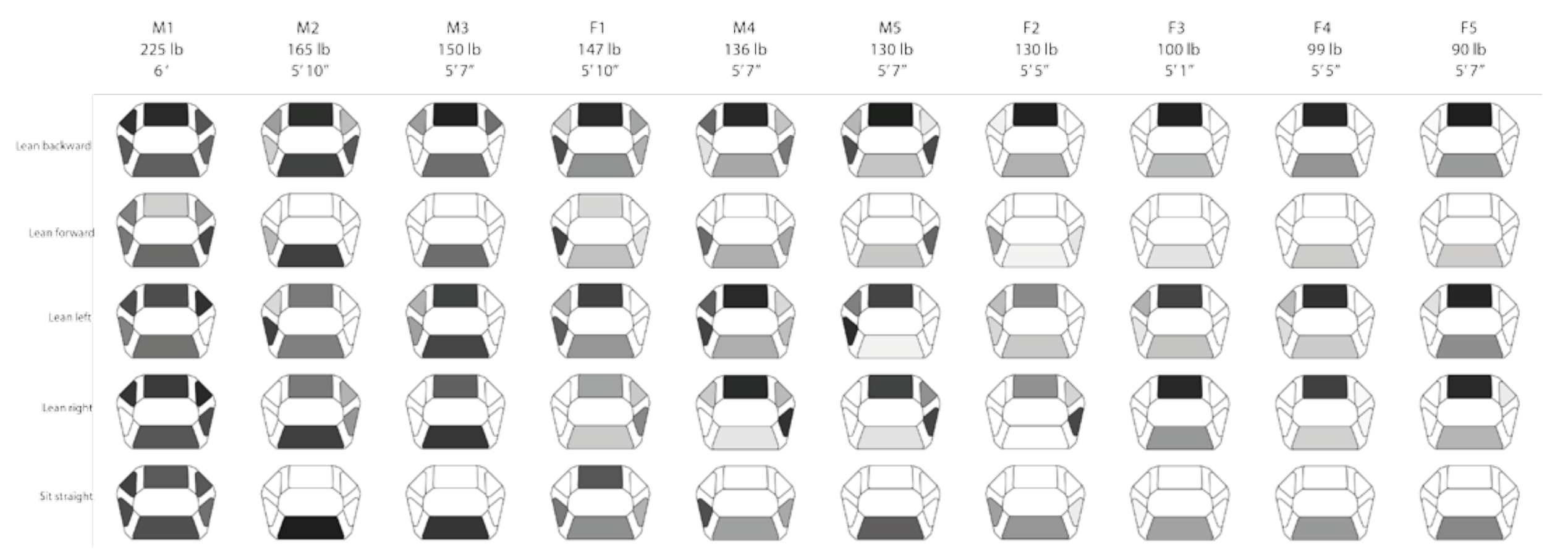
Results show that BodyPods are highly accurate in capturing 8 postures and 2 torso rotations (clockwise, counterclockwise). While these 10 movements can be useful in applications in gestural interfaces or game controllers, we conducted a 10-person user study gathering both qualitative and quantitative data from only 5 sitting postures: Sit Straight, Lean Left, Lean Right, Lean Forward, Lean Backward. We did not include other postures as they seemed rather unnatural. Participants sat in each posture for 10 seconds and repeated the posture 3 times. Results encourage our decision to create a parametrically customizable production scheme for BodyPods. We also plan to increase the height of the back pad and use large-bed CNC routers instead of the smaller-size laser cutters. Furthermore, we observed that with one sensor, the bottom cushion pad had occasionally difficulties detecting near-edge sitting postures. This can be improved by either rearranging the sensor under the cushion pad or by introducing a second sensor (one in the front and one in the back edge of the seat). Other areas of future research include the development of learning algorithms for training BodyPods to recognize postures from bodyprint data.





Early user studies with different postures used for calibrating the sensors. Icons on the lower left of each picture illustrate the bodyprint measurements from the pads.

The measurements from the sensors of the black BodyPod in the background (far right) are mapped through color and light to the corresponding pads of the white BodyPod in the foreground (left).



Participant's bodyprints for 5 postures. The darker the pad, the more pressure the participant exerted against it. To illustrate the pressure exerted, we mapped the average pressure values per pad ranging from 0 – 1023 to 0 - 256.

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