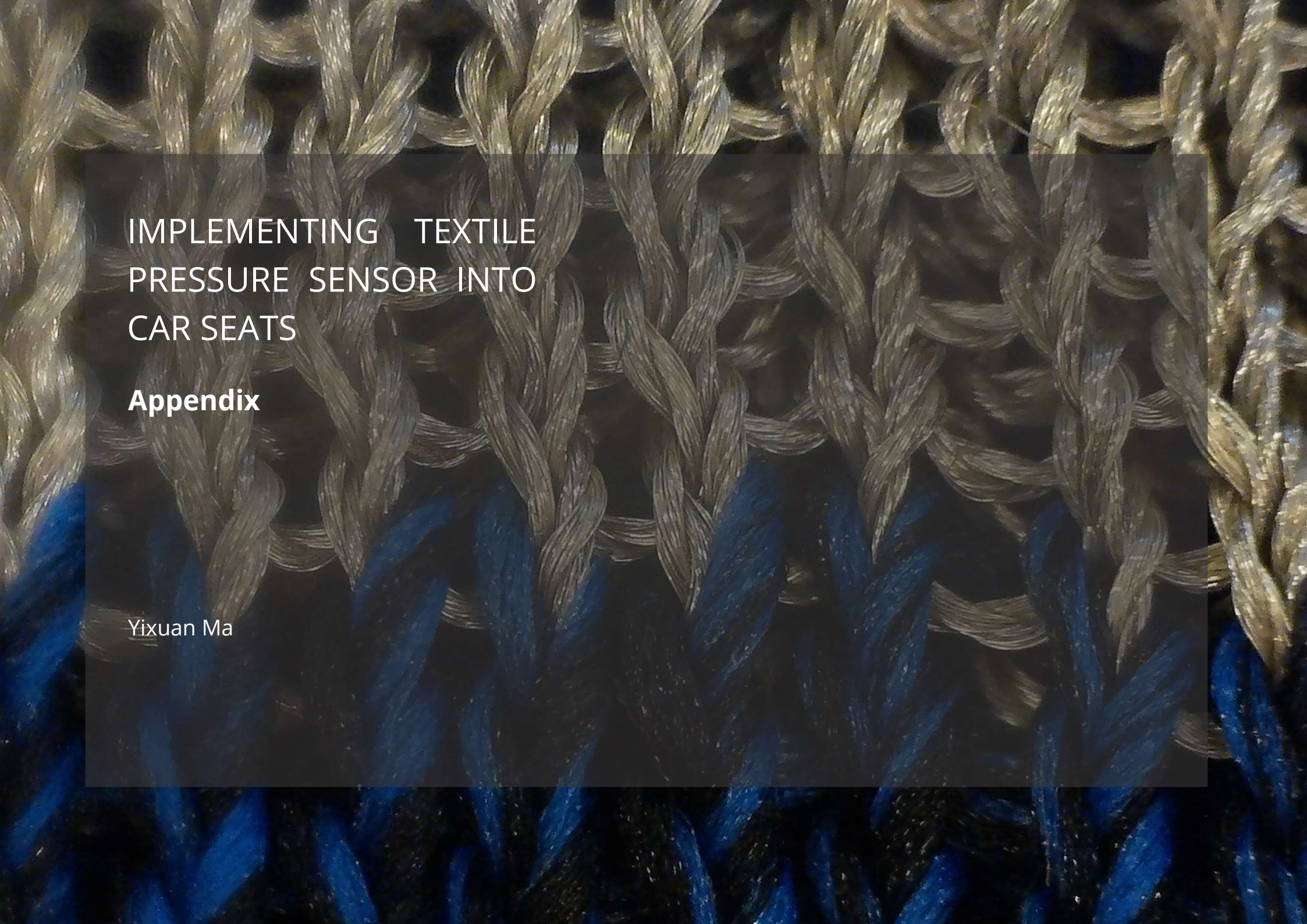


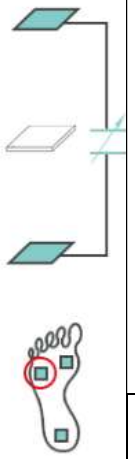
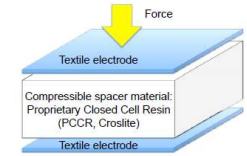
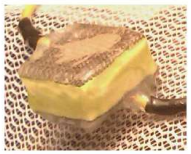
IMPLEMENTING TEXTILE PRESSURE SENSOR INTO CAR SEATS

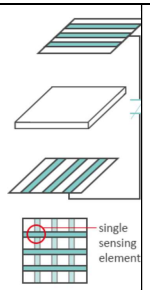
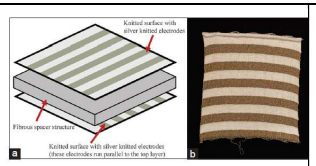
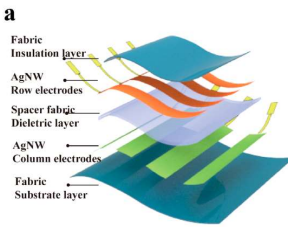
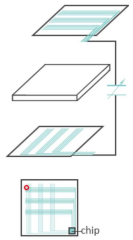
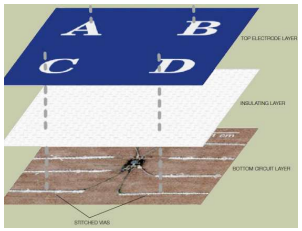
Appendix

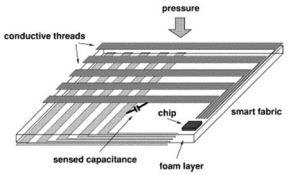
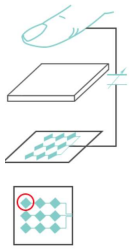
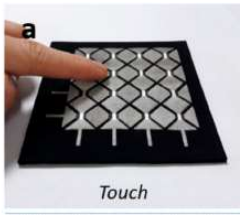
Yixuan Ma

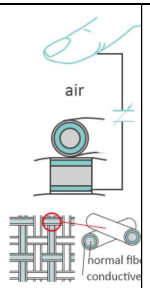
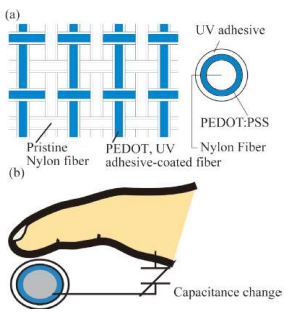
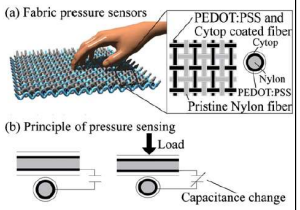
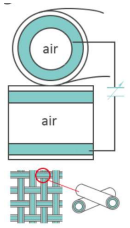
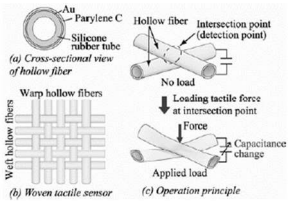
Table of contents

Appendix A Six types of textile pressure based on capacitance change.

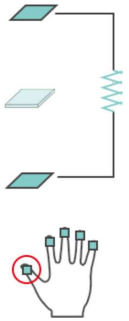
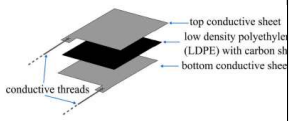
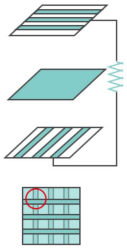
Types of structure			refer	Picture	Material	Sensitivity	Sensing range	Size	Advantage	Disadvantage
1.	Single element sensor		(Thomas Holleczek, 2010)	 	c- silver coated textile, d- PCCR(proprietary closed cell resin)	0.05pF/(Ncm2)	0-30N/cm2	10mm x10mm		1.The silicone sealing of the sensors started to peel off after the conduction of the outdoor experiments. 2. some of the wires showed the tendency to break off from the electrodes.3. are not machine washable owing to the wires stitched into them.
			(Meyer, Arnrich, Schumm, & Troster, 2010)		c-silver coated woven, conductive thread d- textile spacer	0.192 pF/(Ncm2) with 20%–30% hysteresis error	0-12N/cm2	Core area:35.1cmx 40.5cm Pixel=2x2 cm	1. can be recognized more in applications where exact pressure values are needed, e.g., decubitus prevention, muscle activity measurements, or control of pressure in medical stockings, 2. Standard textiles that are not specially optimized for low hysteresis can be used	but is not as significant for posture classification.

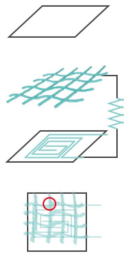
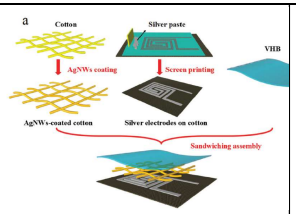
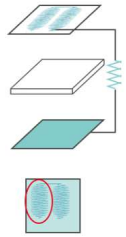
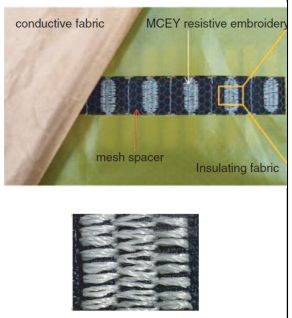
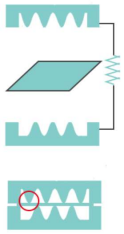
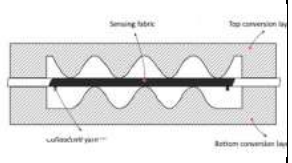
2	conductive stripe matrix		(Hughes-Riley, Oliveira, Morris, & Dias, 2019)		c- silver knitted electrodes d- Knitted fabric, Fibrous spacer structure	0.13-1.5pF/kPa=1.3-15pf/cm2	Max 25kPa (3.2mm)2.5 N/cm2	170.0mm × 155.0 mm, 5 stripes with 12mm wide	showed no significant hysteresis effects. (compare to pocket sensor)	spacer, thinner- more sensitive, thicker- operate at higher pressure
			(Wu et al., 2019)		c- Ag NFs were constructed on the fabrics d- 3D penetrated fabric dielectric layer	0.283KPa-1,	0-6kPa	2cmx2 cm	good stability (≥20 000 cycles) good biocompatibility with human skin. acquisition of human motions and health data.	
3	e-broidery		(E. R. Post, 2000)		c-conductive thread d-cloth	Switching voltage threshold of a CMOS logic buffer	Constant sensing	mm-cm range	Increase the overall conductivity of the sewn circuit element. "Robust" The opportunity not only to measure the applied	will not currently function when wet, but works fine when dried again mechanical flexibility is expected to be worse (M.

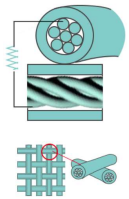
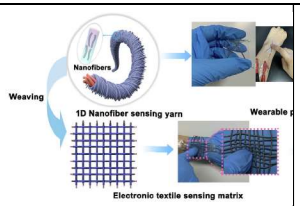
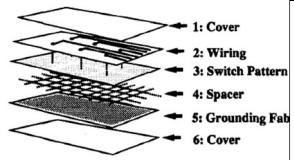
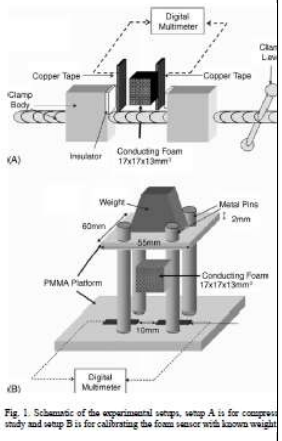
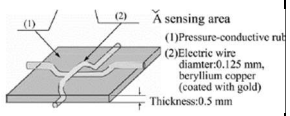
			(Sergio et al., 2003)		c- conductive thread d- cloth	0.214 V /pF (pixel) for Cf=3.37 pF Cf= 25.2 fF to 12.8 pF	Max 13.6k Pa	Core area:32mm2, 64x64 pixels	pressure, but also monitor pressure distribution of the surface. (Poupyrev et al., 2016) can be a nice way of connecting	Sergio, 2002) might require more human labor
4	Printed conductive patterns		(Cao et al., 2018)		c- conductive ink, d- nylon	0.0479, 0.0186, and 0.0033kPa-1	Constant sensing	striped array electrode was 1.5 cm with a height of 2, 4, 6, and 8 cm	electrode shows excellent stability under harsh mechanical deformation and even after being washed. highly sensitive touch/gesture sensing performance Site- specific, localized and direct deposition of conductive materials on finished textiles. Reduce consumption of chemical inks. Allow scale and reduction of production cost (Acar et al., 2019) used a lot in ECG monitoring (Acar et al., 2019) (Achilli, Pani, & Bonfiglio, 2017) (Xu, Luo, He, Guo, & Yang, 2019)	
			(Vu & Kim, 2020)		c- Silver/SWCNT, d-PET/SP fabric	higher than (0.283 kPa-1 at 5 kPa) and (121x10-4 kPa-1 at 100 kPa) , lower than (0.007 kPa-1 at 5 kPa).	0-100kPa	a width of each sensing plate (column/row) of 12 mm, and a gap between two plates of 5 mm		

5	fiber coated with conductive material		(Seiichi Takamatsu, 2011)		c-PEDOT, d- Nylon	0:02 pF /mm, w.r.t. object width	0-2pF	Core: 470µm diameter, Pitch =5cm	can be used in large area sensing(1.2mx3m)	more of touch sensing instead of pressure sensing, the response if capacitive sensor was defined by the area of the touch sensor area
			(Takamatsu, Kobayashi, Shibayama, Miyake, & Itoh, 2012)		PSS and Cytop coated fiber, c- PSS, a conductive polymer. d- nylon	capacitance changes that ranged from 0.19 to 1.84 pF	0.98-9.8N/cm2	16 cm ×16 cm.	touch sensors can be used in applications from wearable keyboards to sensors embedded in beds for health care purposes	low sensing range, more for human touch
6	hollo conductive fiber		(Kim et al., 2018)		c-thin film deposited metals, d-parylene substrate-silicone rubber	0.011ΔC m/N	0-50mN	Diameter =250µm, thickness= 40µm	1000 times of repeated sit-down measurements and washing with detergent, the performance of the textile pressure sensor was perfectly maintained	high requirement for the fibers

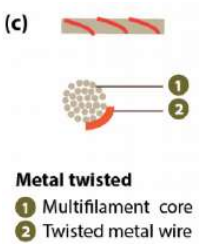
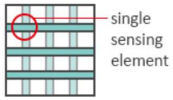
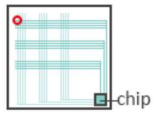
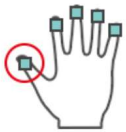
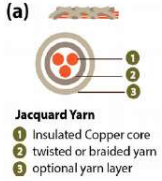
Appendix B Six types of textile pressure sensor based on resistance change

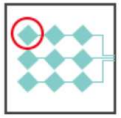
Types of structure			refer	Picture	Material	Sensitivity	Sensing range	Size	Advantage	Disadvantage
1.	Single element sensor		(Pizarro et al., 2018)	 	Conductive sheet, Low density polyethy sheet with carbon sheet	1kPa	70kPa	2.5cmx3.3cm	easy to build, was done using only standard office tools and done by hand. does not take more than 15 min for a person who reads the building instructions for the first time.	One-point detection, recovery time varies
2	conductive stripes with piezo resistive middle layer		(Maurin Donneaud, 2017)	 Figure 3: Multi-layer structure of eTextile sensor: n conductive (outside), piezo resistive (center) and conduc (in strips) materials combine to form the sensor.	piezo resistive material conductive &nonconductive strips	0.5kg (64 €0.50 coins) around 0.68Kpa	2kg(coins) around 2.72KPa	strip width 30mm	allows it to be draped over the body, be it as clothing or as a soft, malleable wearable	very difficult to embed into elastic fabric because strong mechanical stresses, such as impacts and compressions can seriously damage these sophisticated sensors. (Sergio et al., 2003)

3	screen printed pattern with coated cotton		(Zhou et al., 2018)		Ag NWs-coated cotton, silver electrodes screen printed, VHB	0.76Pa	0-30kPa	"4x4 pixel sensing arrays (5x 5 mm2 each)"	entire fabrication process is facile, economical and suitable for large-scale integrated production	
4	E-broidery		(Roh, 2013)		Conductive fabric, mesh spacer, MCEY resistive embroidery		Constant sensing	8mmx16mm/element	touch sensitive instead of pressure sensing	
5	tooth structured sensor		(Y. Wang et al., 2011)		strain sensing fabric, tooth structured foam	>2.98x10-3kPa-1	0-2000kPa	10x16x4.8mm3	By adjusting the Young's modulus of the two conversion layers, the geometrical dimensions, the measurement ranges, and sensitivities of the sensors can be quantitatively determined.	based on strain sensing fabric, complicated coating and manufacturing process

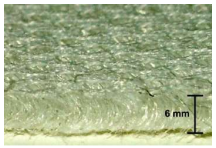
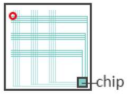
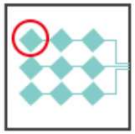
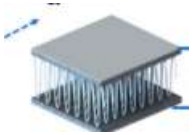
6	Nano fiber		(Qi et al., 2020)		c-thin film deposited metals, d- parylene substrate- silicone rubber (Castano & Flatau, 2014)	16.52/ N	0.03~5N	a textile sensing matrix with 9 x 9 pixels	a fast response speed (~0.03 s), and excellent stability.	
7	Switch tactile sensor		("<00_Switch tactile.pdf>,")		plate fabirc Cu, Ni; Base Polyester Net e192	Thres hold at 500 g/mm 2	70~500g/ mm2	Sensing cell: 2.3mmx 4.35mm		
8	Polyuret hane foam		(Brady, Diamond, & Lau, 2005)		Soft elastomer base Ppy	0.000 7mSN- 1	1000- 7000N/m 2	1.7cmx1 .7cmx1. 3cm		
9	Conduct ive rubber based		(Shimojo, Namiki, Ishikawa, Makino, & Mabuchi, 2004)		Polyurethane Carbon polymer with beryllium Au-coated copper wire	0.25k ΩMPa -1	0-0.2MPa	3mm x3mm		

Appendix C Types of yarns and spacers

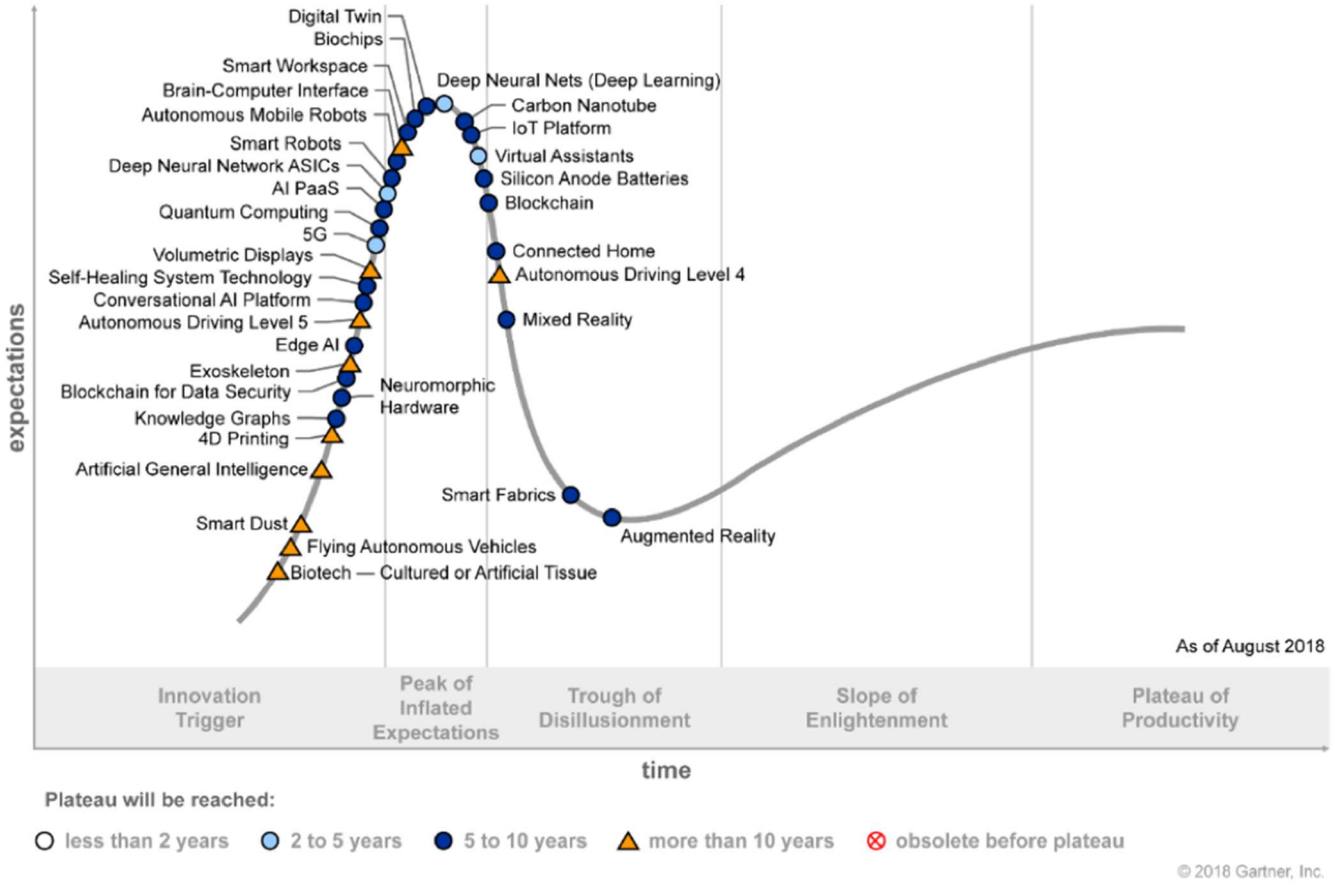
Reference	Brand	Material	Structure	Resistance	Sensor structure	Advantage	Disadvantage
(Meyer et al., 2010)	Statex, type Shieldex 235/34dtex 2ply HC	multifilament yarn coated with silver.		120 Ω/m		resistance increases only a few percent after washing ten times.	
(Hughes-Riley et al., 2019)	Shieldex® yarn, Shieldex® 235/32 dtex–2–ply–HC +B silver , Bremen, Germany						
(E. R. Post, 2000)	Bekaert BK50/2	Stainless steel in a polyester mesh		50 Ω/m		performs the best under machine sewing and passes through ordinary sewing needles.	highly resistive short circuits can occur between sewn traces
(Pizarro et al., 2018)	conductive Shieldex NoraDell woven fabric sheets			surface resistance lower than 0.009 Ω/sq		good conductivity and radiation efficiency characteristics	
	Shieldex 117/17 DTEX conductive threads						
							

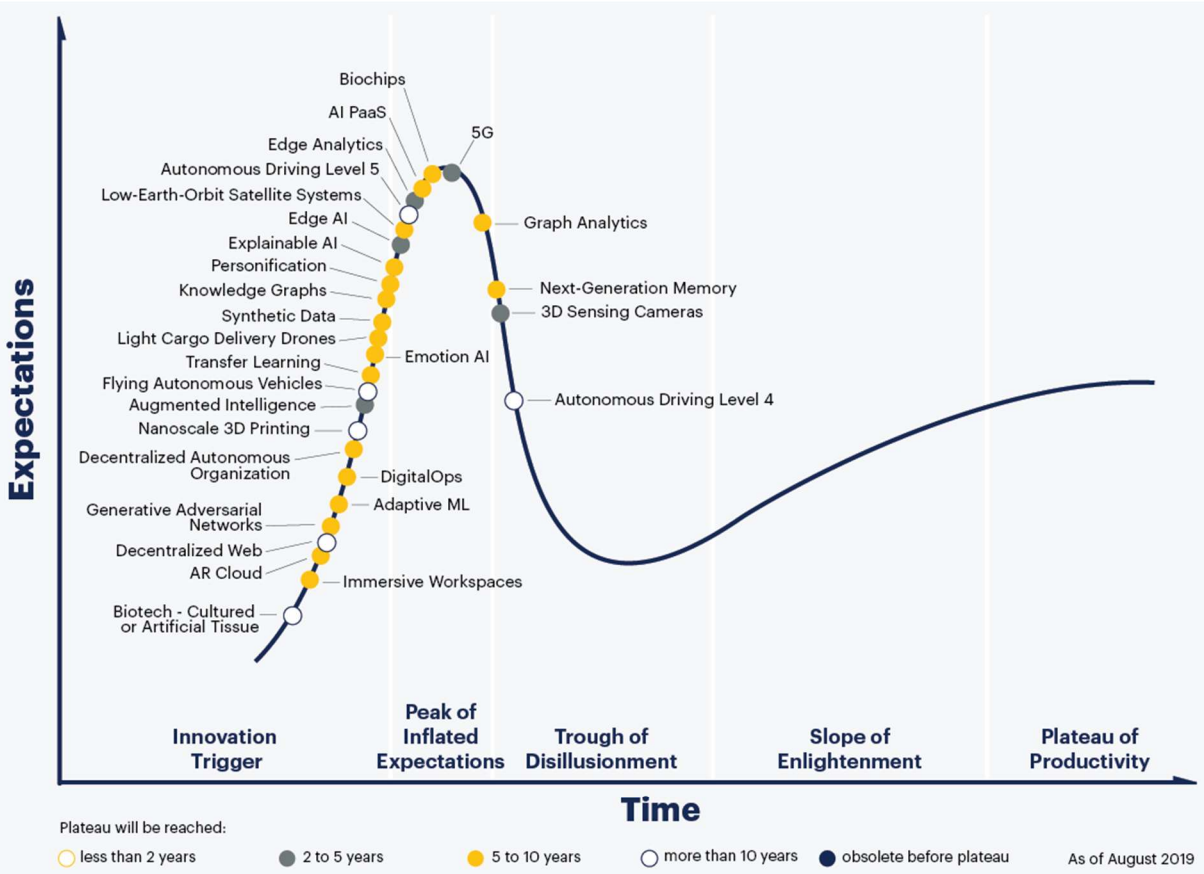
	AgNWs					have superior conductivity as well as excellent stability, which are ideal candidates for wearable pressure sensors.	
(Vu & Kim, 2020)	SWCNT/stretchable silver paste	CNT covered by silver paste				Cover the CNT with silver, not toxic	
(Cao et al., 2018)	CNT ink, printed on nylon	carbon nanotubes,	polyurethane (PU) was added in the synthesis procedure of the CNT ink	~ 750 Ω/m		exhibits excellent performance under harsh mechanical deformation (wash)	Resistance varies when printed on different materials. CNTs are toxic for the skin. (Vu & Kim, 2020)

Types of spacers

Reference	Brand	Material	Picture	Thickness	Characters	Sensor structure	Advantage	Disadvantage
(Meyer et al., 2010)	Textile spacer (Müller Textil, Germany),	Polyester pile yarns		6 mm	compressibility of 50% at 2.3N/cm^2			turned out to be too soft in sport situations (Thomas Holleczek, 2010)
(Thomas Holleczek, 2010)	Croslite™, also referred to as Proprietary Closed Cell Resin (PCCR)	Proprietary Closed Cell Resin (PCCR)		5mm	is sensitive up to a pressure of 60Ncm−2		It is light, antimicrobial, abrasion proof, resists salt water	
(Sergio et al., 2003)	Foam							
(Cao et al., 2018)	Nylon							
(Vu & Kim, 2020)	PET/SP spacer	two independent PET/SP fabric layers with a spacer layer (PET yarns)		5mm				
(Pizarro et al., 2018)	Antistat black conductive bag (ANT006BCB)	Low Density Polyethylene (LDPE) sheet with a 0.1016 mm carbon layer			surface resistivity of 104 to 106 Ω	widely used for anti-static applications		

Appendix D Gartner Hype Cycle for Emerging Technologies 2018, 2019





gartner.com/SmarterWithGartner

Source: Gartner

Gartner

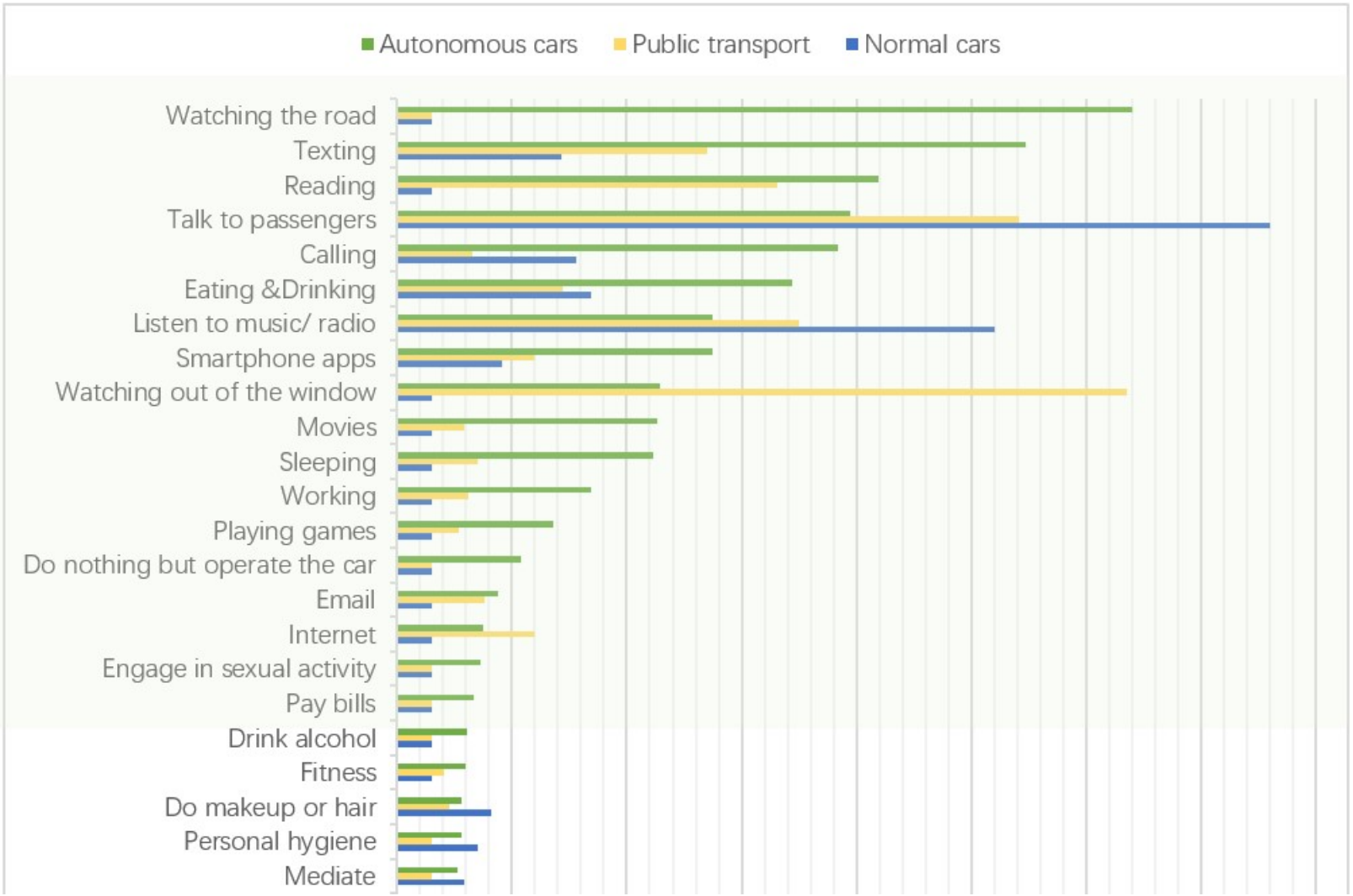
Appendix E Summary of researches on activities people are doing or would like to do in cars and public transportation.

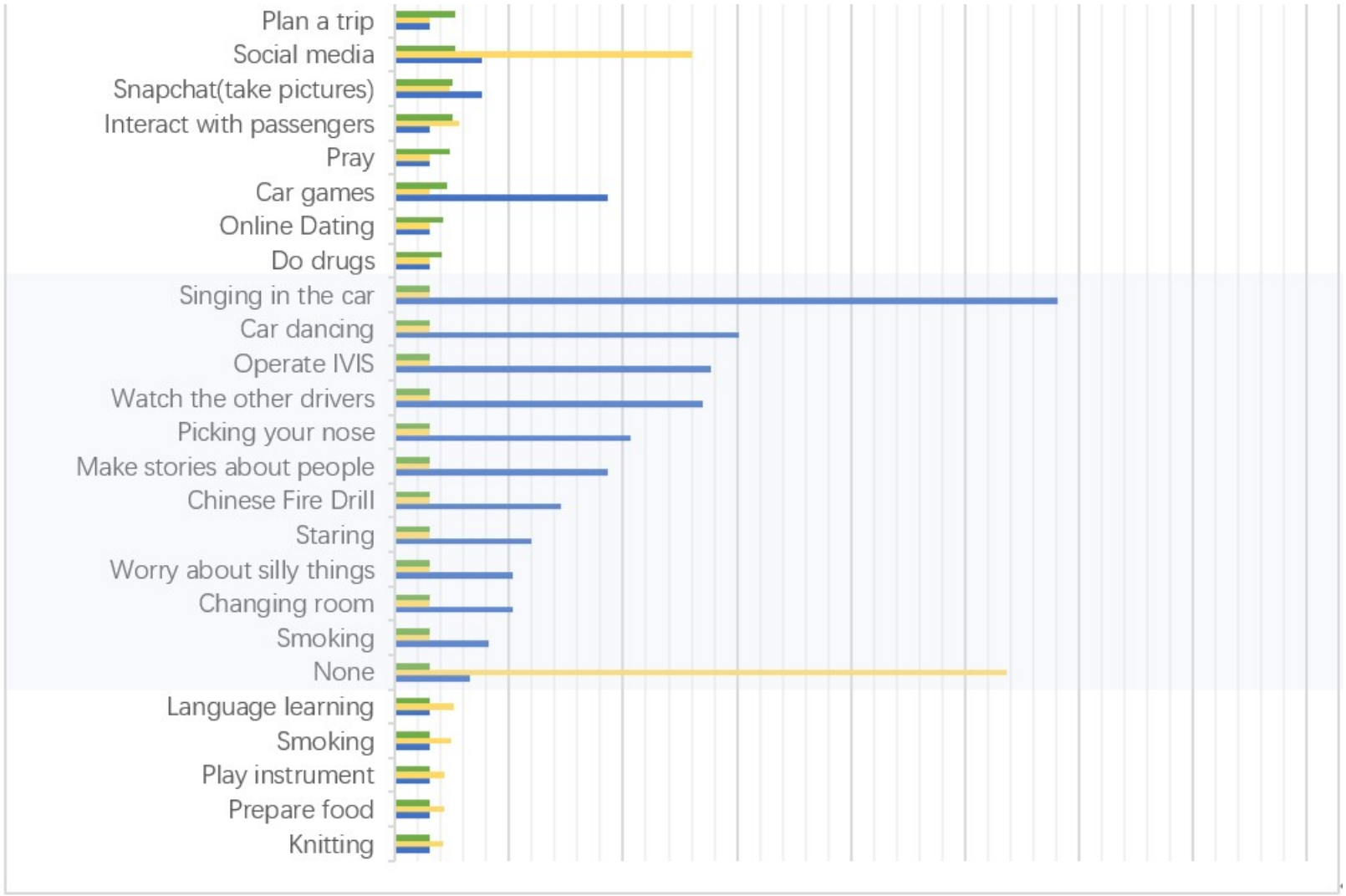
Normal cars			Public Transport			Autonomous cars						
[3]2015Germany, Online, 300P	[7]2016	[9]	[3]2015Germany	[3]2015Germany Interview	[3]2015Germany Observation	[1]2014 us,uk	[2]2015 US, Germany, China	[3]2015Germany	[4] 2017 US, 2000p	[5] 2017 US 2932p	[6]	[8]
95.3% Listen to music/ radio	Singing in the car	Talking to yourselves or other drivers	Watch out of the window	58% Texting message	18.5% None	41% Watch the road	26% Texting and talking	Music, radio,	36% Watch the road	45% Make calls	Use Mobile devices	Wardrobe changes
95% Talk to passengers	Car dancing	Watch the other drivers	Texting	47% Talk to other people	16.1% Read newspapers etc	22% would not ride a sompletely self- driving vehicle	21% Enjoying or observing the road	Talk to passengers	Read a book	42% Eat	Eat lunch	Diper changes
73% Operate IVIS	Car games	Make stories about people	Music,radio, audio books	42% Social media, other phone apps	14.3% Talking to passengers	8% reading	10% Sleeping	Watch out of the window	Catch up with friends and family via phone	35% Do nothing but operate the car	Read a book	Piano playing
66.7% Eating, Drinking	Chinese Fire Drill	Nose drill	Talk to passengers	35% Calling on the phone	11.5% Looking out of the window	8% Texting or talking with friends or family	8% Movies	Texting	Get work done outside the office	34% Text/email	Watch movies	Arts and crafts
36.7% Calling	Staring	Turn off the music when searching for a parking space	Internet	35% Music, radio	19.3% Using the mobile phone	7% Sleeping	7% Playing games	Internet	Watch a television show	27% Read	Do work	Dog fancing
28.7% Texting	Changing Room	worried about silly things	Social Media		7% Music, radio		7% Working	Eating& Drinking	Watch a movie	21% Watch TV	Pay bills	Eating Soup
15% Smartphone apps	Picking your nose	Singing	Reading		5.8% Eating& Drinking			Calling	Eat	19% Sleep	Play video games	Putting on makeup
8% Smoking		do makeup, or hair	Eating & Drinking					Reading	Play video games	13% Groom	Put on makeup	Reading
5.3% Social media		snapchat	E-mail					Social Media	Sleep	10% Mediate	Plan a trip	Putting both feet up
3% Personal hygiene		write messages	Sleeping					Interact with passengers	Engage in sexual activity	7% Romance	Shoot and post Photos or selfies	Typing and drinking

2.7% None		talk on the phone	Calling					Sleeping	Pray	5% Drink alcohol		Smoking, Dinking, Talking on the phone
		make your own dancing party	Office tasks					Watch movies	Play a card game	2% Exercise		
		scroll through the radio stations until you find the best music	Watch movies					Office tasks	Exercise			
		completely elsewhere in head	Interact with passengers					(Video) games	Drink alcohol			
		set the climate up and down to find perfect temperature	Video games					Take pictures	Online dating			
		hold the steering wheel with knees and eat	Language learning					Smoking	Do drugs			
			Smoking					Learn languages				
			Take pictures					Knitting				
			None					Prepare meals				
			Cosmetics					Cosmetics				
			Play instruments					Play instruments				
			Prepare food					Fitness				
			Knitting									
			Fitness									

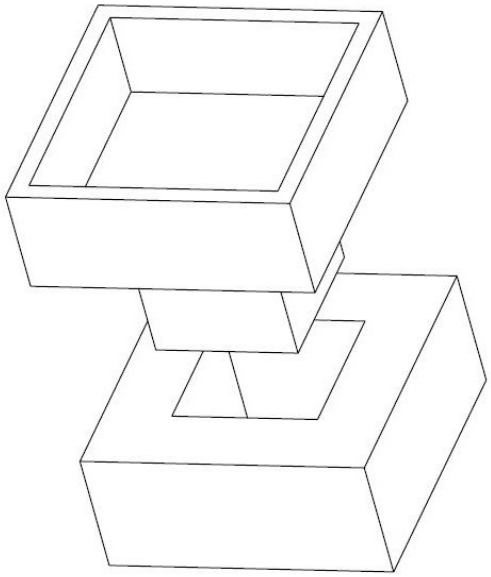
To make the data more comparable, it is calculated and illustrated based on the ranking of activities in each report. The "grade" is $\sum 1/\text{ranking}$.

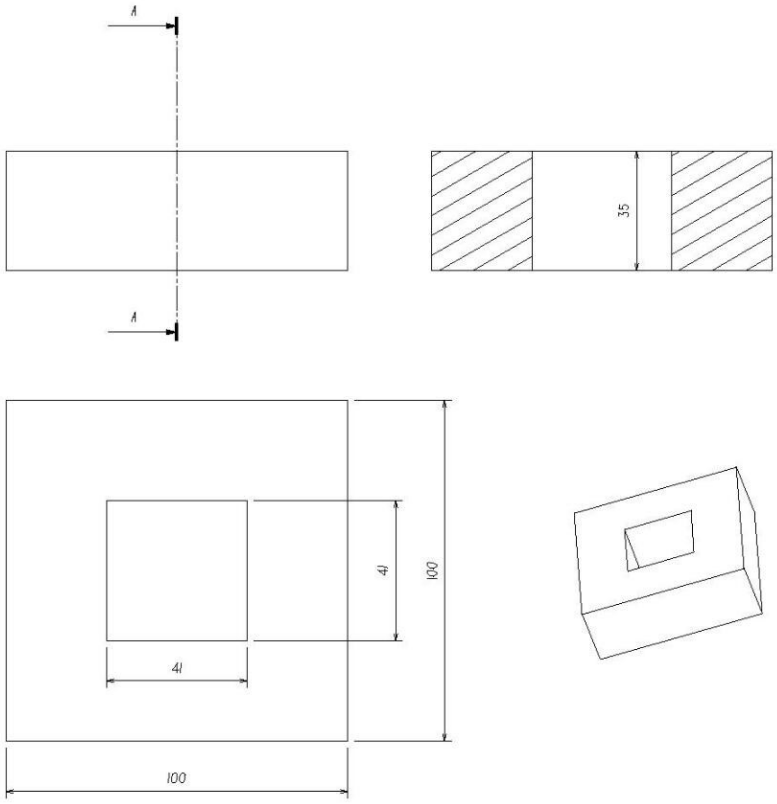
For example, "Texting" ranks the 3rd most popular activity in report 1, it scores 1/3. The total score is the sum of the score from all the reports. Some activities that are not mentioned in some reports, are given a score of 1/50 as there are in total 49 activities mentioned.

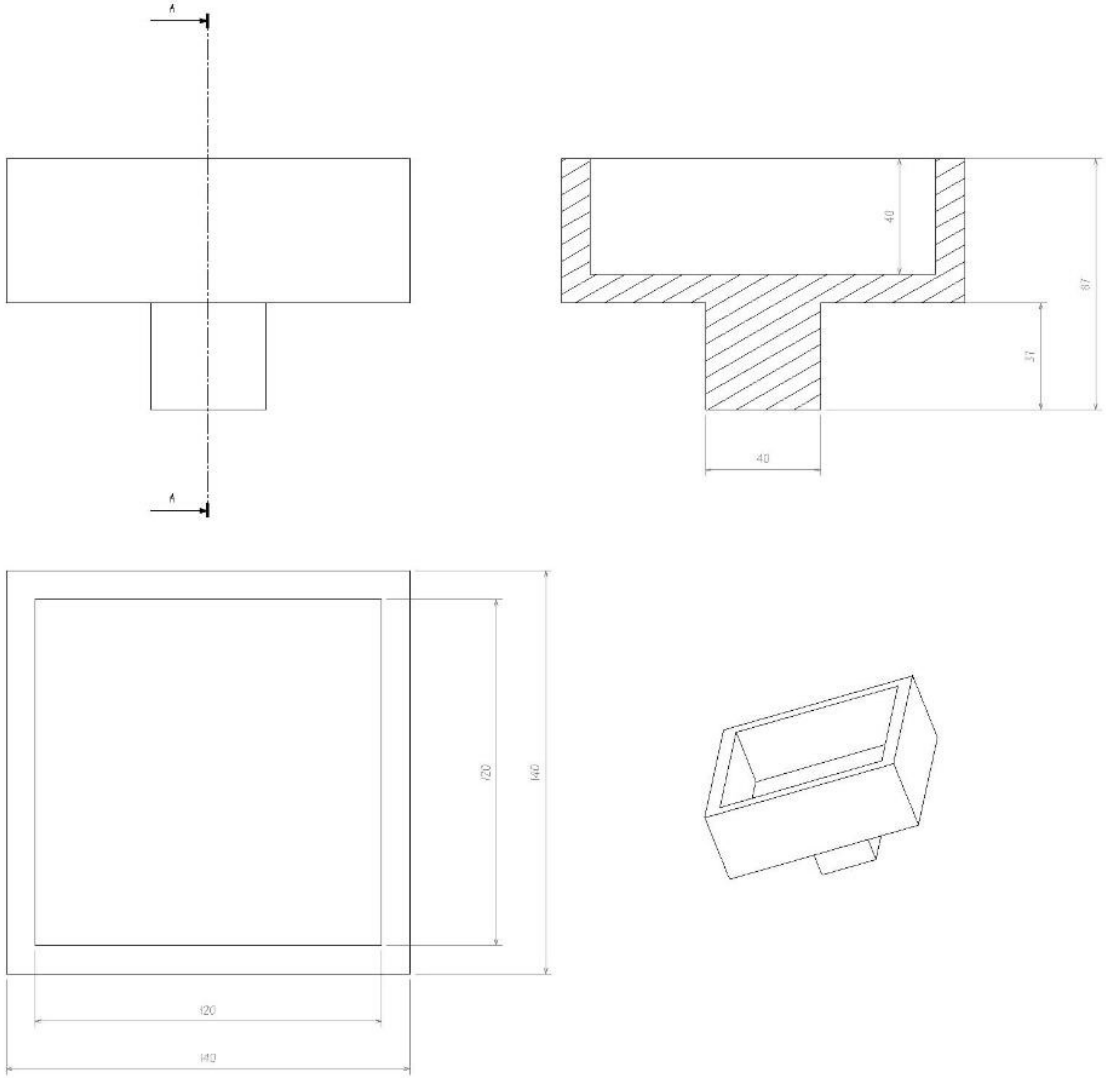



Plan a trip
Social media
Snapchat(take pictures)
Interact with passengers
Pray
Car games
Online Dating
Do drugs
Singing in the car
Car dancing
Operate IVIS
Watch the other drivers
Picking your nose
Make stories about people
Chinese Fire Drill
Staring
Worry about silly things
Changing room
Smoking
None
Language learning
Smoking
Play instrument
Prepare food
Knitting

Appendix F Dimension of the container used for testing

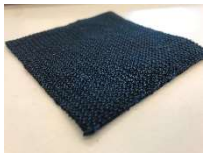
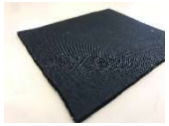


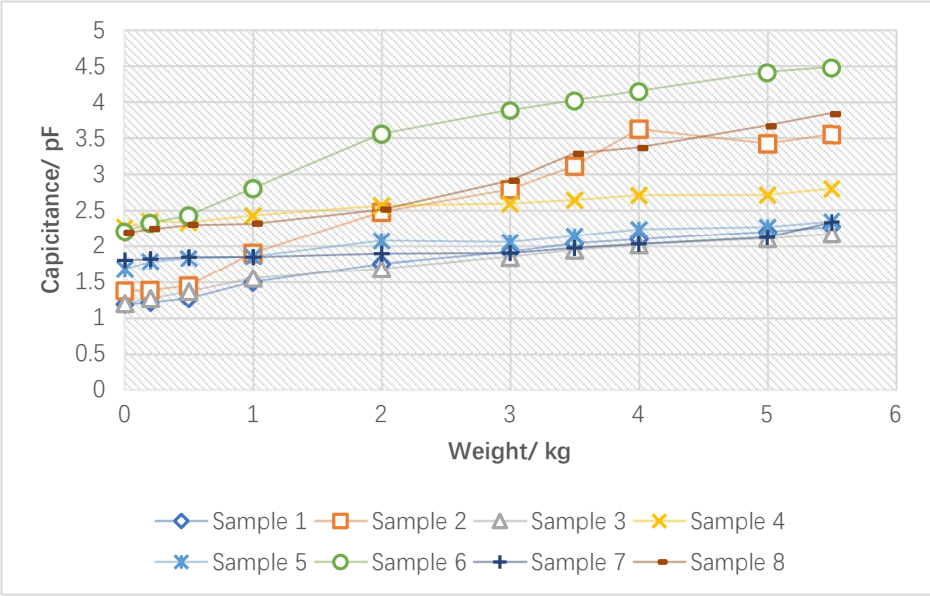
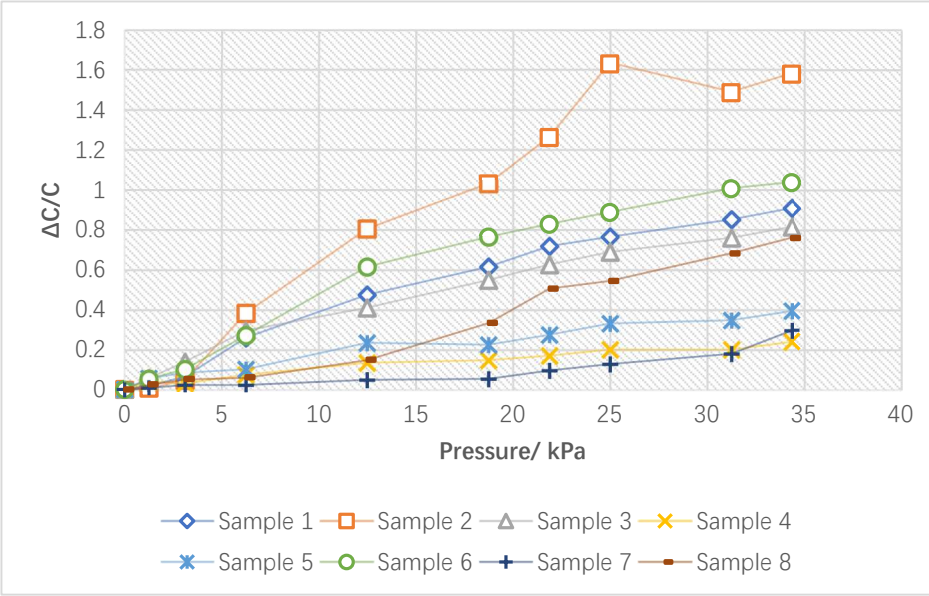



A
A
40
87
37
40
120
140
120
140

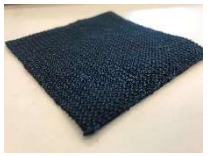
Appendix G Testing data. TEST 1

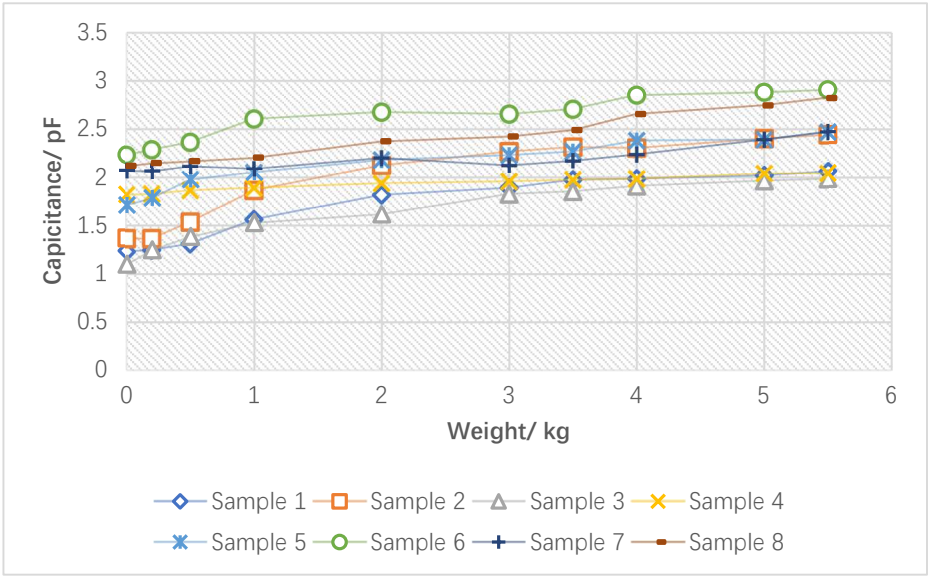
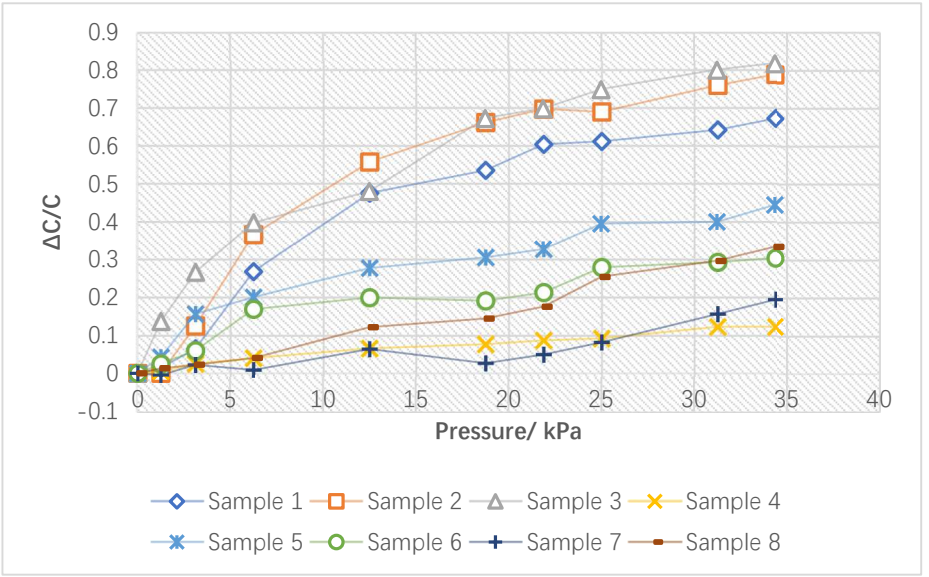
Contact area 10*10

	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5			Sample 6			Sample 7			Sample 8		
																								
	Foam			Foam			Shape-memory foam			Knitted fabric			Fabric with cotton											
Contact area	10*10			10*10			10*10			10*10			10*10			10*10			10*10			10*10		
Thickness of Spacer	5 mm			2 mm			10 mm			2 mm			2 mm			2mm			3mm			2 mm		
Weight/kg	Capacitance change /pF																							
0	1.153	1.205	1.205	1.418	1.364	1.338	1.205	1.205	1.179	2.218	2.275	2.275	1.634	1.743	1.661	2.105	2.218	2.275	1.798	1.798	1.798	2.077	2.190	2.275
0.2	1.232	1.205	1.205	1.444	1.364	1.338	1.232	1.364	1.205	2.333	2.304	2.419	1.826	1.716	1.798	2.218	2.304	2.448	1.826	1.853	1.771	2.105	2.275	2.333
0.5	1.258	1.311	1.232	1.418	1.391	1.525	1.444	1.418	1.232	2.304	2.333	2.361	1.853	1.853	1.771	2.333	2.477	2.477	1.881	1.881	1.771	2.133	2.361	2.390
1	1.444	1.525	1.525	1.826	1.965	1.909	1.634	1.552	1.471	2.448	2.419	2.419	1.826	1.909	1.826	2.594	2.860	2.949	1.881	1.826	1.826	2.218	2.333	2.390
2	1.688	1.743	1.826	2.333	2.477	2.623	1.688	1.771	1.606	2.506	2.594	2.594	2.077	2.077	2.077	3.470	3.564	3.627	1.881	1.853	1.937	2.304	2.564	2.652
3	1.853	1.937	1.965	2.860	2.711	2.800	1.909	1.909	1.743	2.535	2.623	2.623	2.049	2.077	2.049	3.913	3.753	3.978	1.909	1.881	1.909	2.652	2.949	3.131
3.5	1.909	2.133	2.077	2.979	3.040	2.949	1.937	2.105	1.798	2.652	2.652	2.623	2.133	2.218	2.077	3.913	4.173	3.978	1.937	1.993	1.993	3.040	3.377	3.439
4	2.021	2.133	2.133	3.315	3.131	3.408	2.077	2.133	1.853	2.652	2.711	2.770	2.275	2.304	2.133	4.108	4.206	4.141	2.021	2.049	2.021	3.284	3.408	3.408
5	2.049	2.275	2.275	3.439	3.192	3.627	2.133	2.275	1.909	2.682	2.711	2.741	2.275	2.247	2.275	4.539	4.371	4.338	2.162	2.133	2.077	3.753	3.532	3.722
5.5	2.105	2.448	2.247	3.346	3.222	4.075	2.247	2.275	1.993	2.800	2.800	2.800	2.390	2.304	2.333	4.471	4.471	4.505	2.304	2.190	2.506	3.817	3.658	4.043

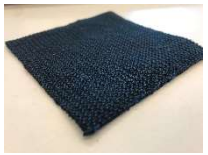
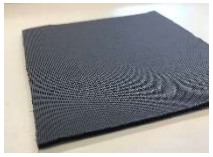
*Contact area 10*10*	
	

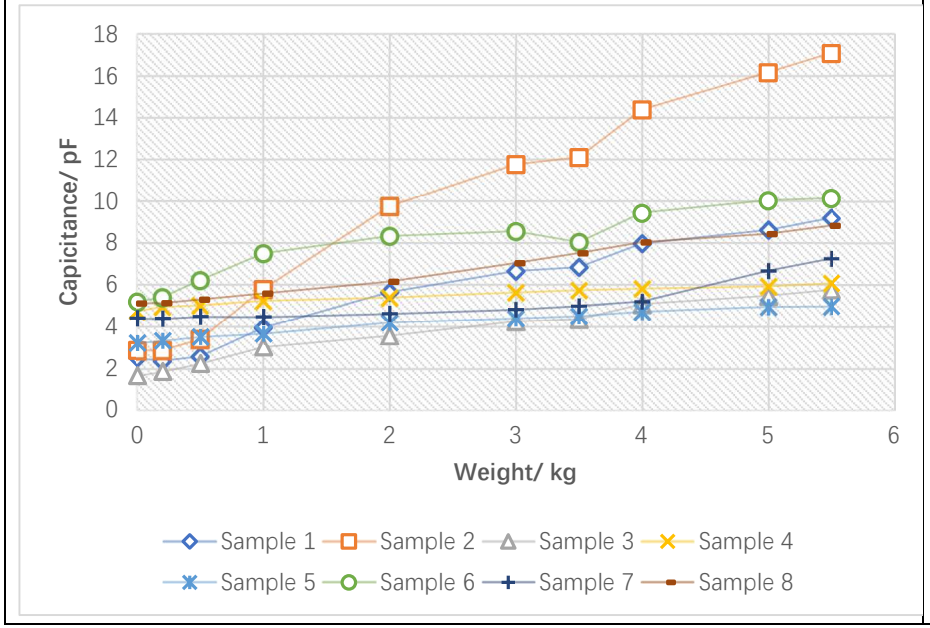
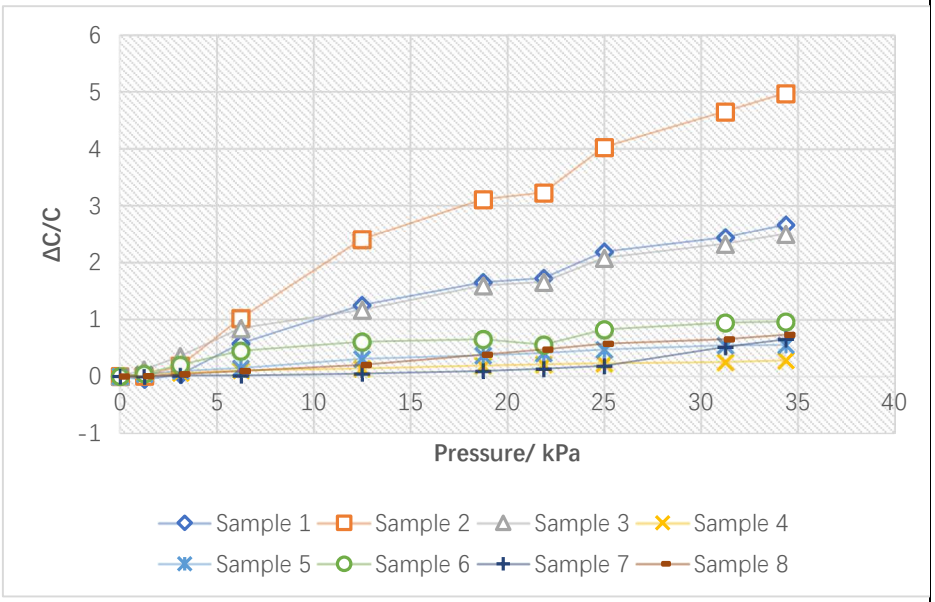
Contact area 20*20

	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5			Sample 6			Sample 7			Sample 8		
																								
Contact area	20*20			20*20			20*20			20*20			20*20			20*20			20*20			20*20		
Thickness of Spacer	8.5 mm			5.5 mm			50 mm			2 mm			5.5 mm			2mm			3mm			2 mm		
Weight/kg	Capacitance change /pF																							
0	1.284	1.205	1.205	1.364	1.364	1.364	1.1	1.074	1.1	1.826	1.826	1.798	1.471	1.826	1.826	2.133	2.304	2.247	2.105	2.077	2.021	2.133	2.133	2.077
0.2	1.232	1.232	1.284	1.364	1.364	1.364	1.205	1.284	1.232	1.826	1.826	1.826	1.498	1.881	1.965	2.19	2.304	2.361	2.077	2.077	2.021	2.162	2.162	2.105
0.5	1.311	1.311	1.311	1.418	1.525	1.661	1.258	1.444	1.444	1.798	1.909	1.881	2.049	1.937	1.937	2.333	2.361	2.39	2.133	2.105	2.105	2.162	2.162	2.162
1	1.471	1.606	1.606	1.743	1.881	1.965	1.525	1.498	1.552	1.826	1.937	1.909	2.105	2.021	2.021	2.594	2.623	2.594	2.049	2.077	2.133	2.133	2.247	2.218
2	1.798	1.853	1.798	2.133	2.077	2.162	1.579	1.579	1.688	1.937	1.909	1.965	2.275	2.133	2.133	2.652	2.652	2.711	2.162	2.275	2.162	2.361	2.419	2.333
3	1.853	1.909	1.909	2.247	2.275	2.275	1.771	1.826	1.881	1.965	1.937	1.965	2.304	2.162	2.218	2.419	2.741	2.8	2.077	2.19	2.105	2.39	2.361	2.506
3.5	1.937	2.021	1.965	2.304	2.304	2.333	1.798	1.853	1.909	1.937	1.965	2.021	2.361	2.19	2.247	2.594	2.77	2.741	2.19	2.247	2.077	2.477	2.477	2.506
4	1.965	1.937	2.049	2.275	2.275	2.361	1.909	1.881	1.937	1.937	2.049	1.965	2.506	2.333	2.304	2.8	2.86	2.889	2.133	2.333	2.247	2.682	2.652	2.623
5	1.993	2.021	2.049	2.39	2.39	2.419	1.937	1.965	1.993	2.021	2.077	2.021	2.419	2.419	2.333	2.889	2.919	2.83	2.304	2.506	2.361	2.594	2.83	2.8
5.5	1.965	2.105	2.105	2.419	2.419	2.477	1.993	1.937	2.021	2.049	2.021	2.049	2.535	2.477	2.39	/	2.889	2.919	2.275	2.685	2.448	2.77	2.889	2.8

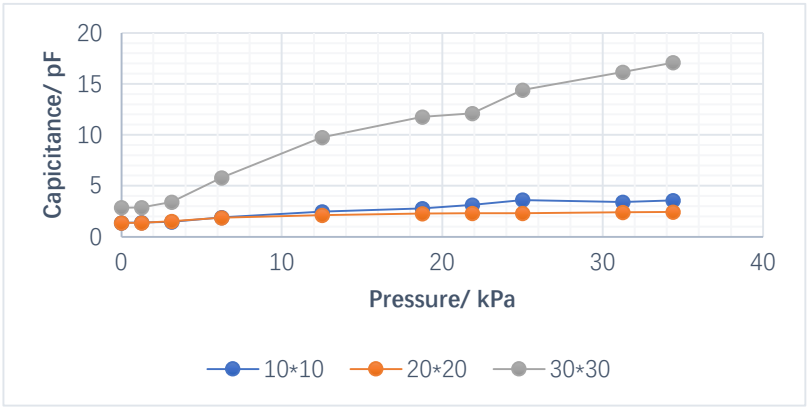
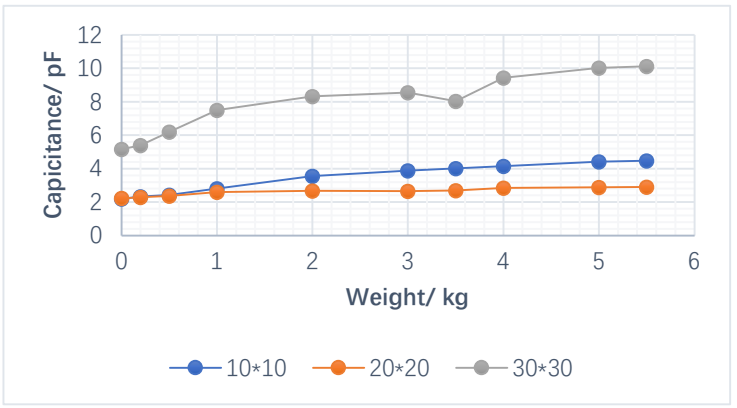
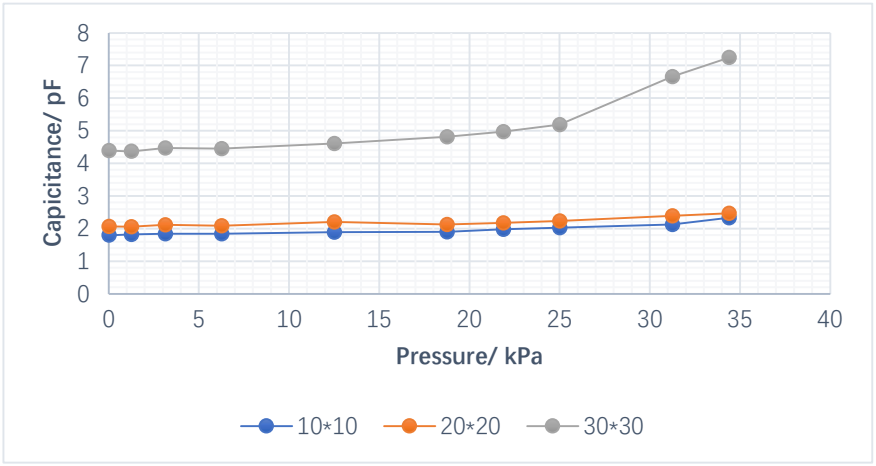
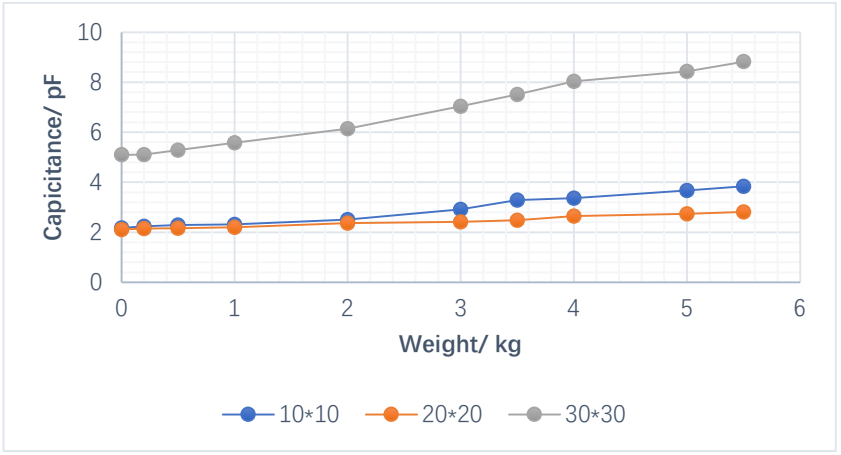
*Contact area 20*20*	
	

Contact area 30*30

	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5			Sample 6			Sample 7			Sample 8		
																								
Contact area	30*30			30*30			30*30			30*30			30*30			30*30			30*30			30*30		
Thickness of Spacer	5 mm			5 mm			5 mm			2 mm			5 mm									5 mm		
Weight/kg	Capacitance change /pF																							
0	2.506	2.506	2.506	2.594	2.830	3.161	1.688	1.606	1.634	4.572	4.742	4.879	3.161	3.222	3.222	4.879	5.440	5.192	4.239	4.438	4.505	5.157	4.948	5.192
0.2	2.361	2.390	2.361	2.623	2.919	3.070	1.606	1.993	1.909	4.776	4.982	5.052	3.192	3.408	3.346	5.192	5.620	5.369	4.272	4.405	4.438	5.157	4.982	5.192
0.5	2.390	2.770	2.594	2.860	3.722	3.595	2.162	2.333	2.162	5.052	4.948	5.017	3.377	3.627	3.501	5.656	6.707	6.248	4.371	4.505	4.539	5.192	5.298	5.369
1	3.010	4.505	4.338	4.572	7.180	5.584	3.100	3.070	2.919	5.122	5.227	5.333	3.627	3.627	3.722	7.180	7.750	7.544	4.371	4.505	4.471	5.440	5.476	5.802
2	5.227	5.656	6.023	9.271	10.015	9.920	3.817	3.253	3.595	5.298	5.440	5.404	4.108	4.272	4.206	7.792	8.955	8.213	4.471	4.674	4.674	5.802	6.172	6.437
3	6.323	6.668	6.942	11.657	11.867	11.762	4.844	3.785	4.141	5.692	5.584	5.584	4.272	4.505	4.405	7.834	9.271	8.558	4.606	4.708	5.122	6.746	7.260	7.100
3.5	6.552	6.552	7.381	11.709	12.133	12.457	4.844	4.010	4.239	5.949	5.656	5.584	4.371	4.505	4.640	8.256	8.822	7.021	4.606	4.844	5.476	7.463	7.834	7.220
4	7.834	7.917	8.171	13.989	14.467	14.711	5.512	5.262	4.405	5.949	5.802	5.656	4.742	4.708	4.708	9.362	9.967	8.955	5.122	5.122	5.333	7.585	8.213	8.299
5	8.646	8.428	8.778	16.043	16.174	16.307	6.023	5.476	4.879	5.986	5.912	5.838	4.879	5.017	4.948	10.302	10.302	9.454	6.248	6.785	6.942	8.001	8.822	8.471
5.5	9.135	9.045	9.362	17.189	17.120	16.982	6.323	5.912	5.017	6.098	6.135	5.949	4.948	4.879	5.052	10.254	10.350	9.779	6.942	7.301	7.503	8.515	9.045	8.911

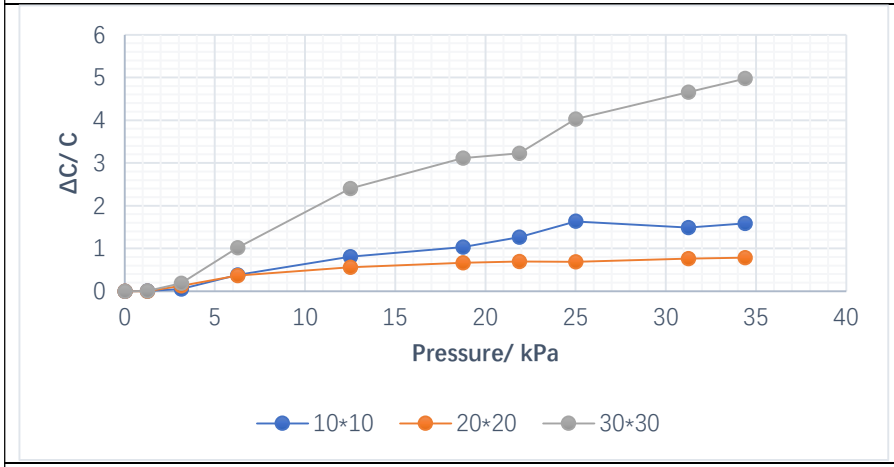
*Contact area 30*30*	
	

Comparing different contact area with same spacer.

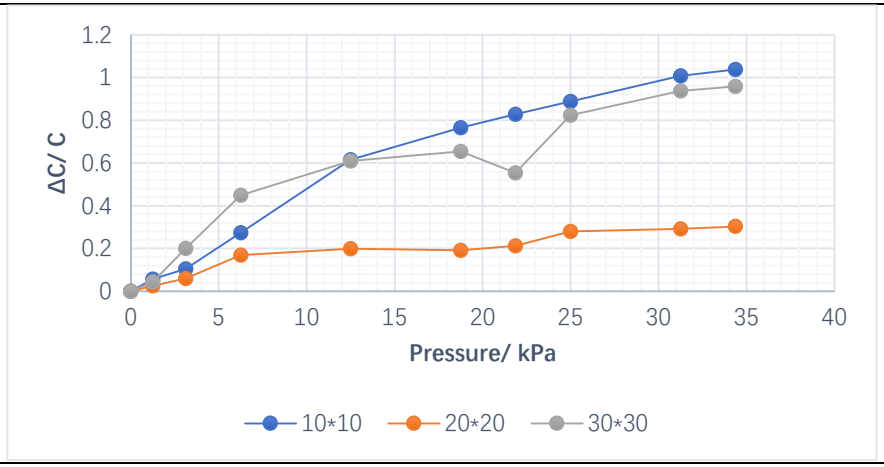
Spacer 2	Spacer 6
	
Spacer 7	**Spacer 8**
	

Comparing same spacer with different contact area

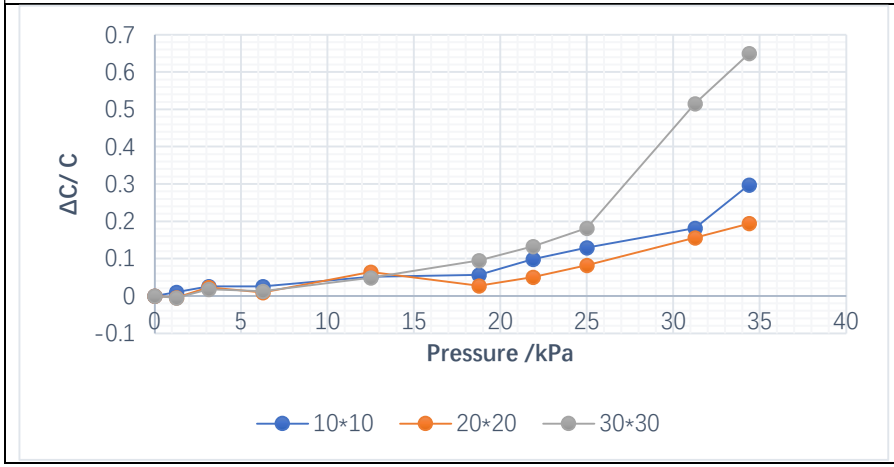
Spacer 2



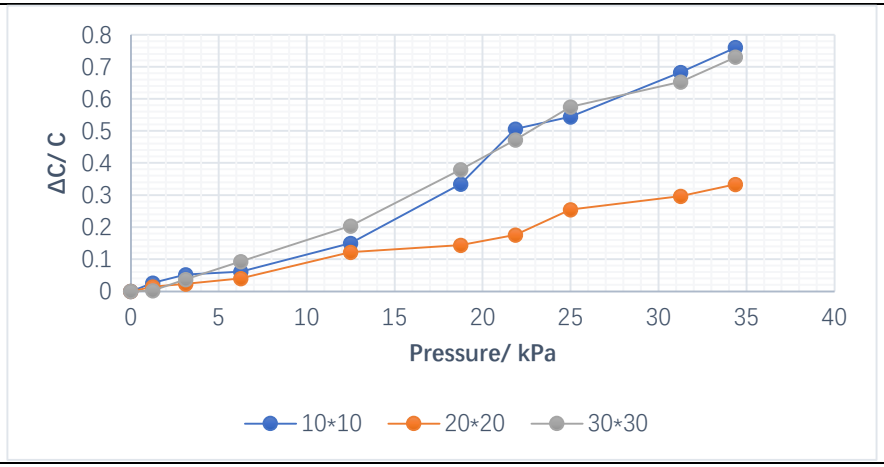
Spacer 6



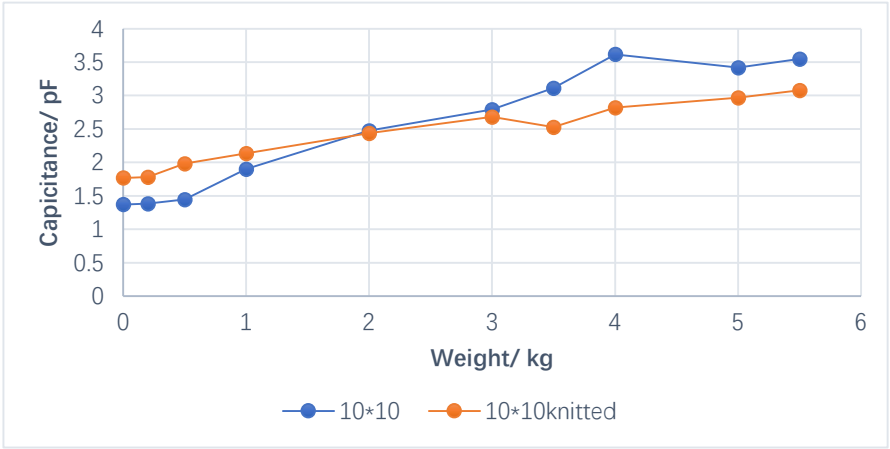
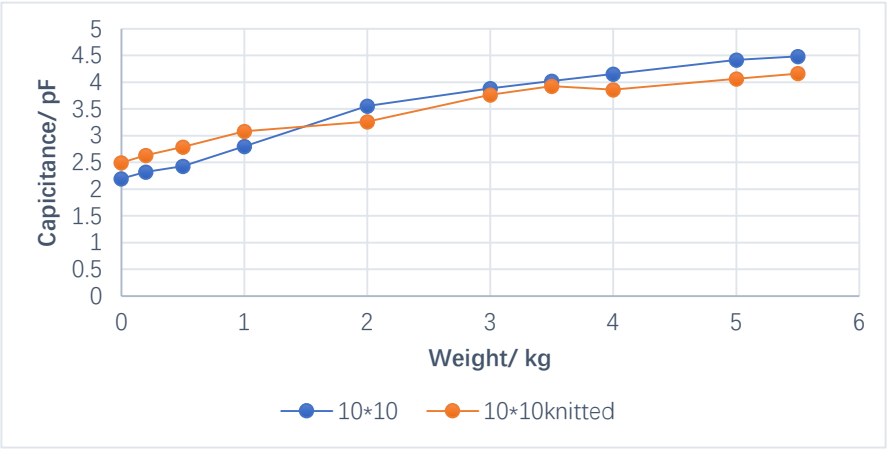
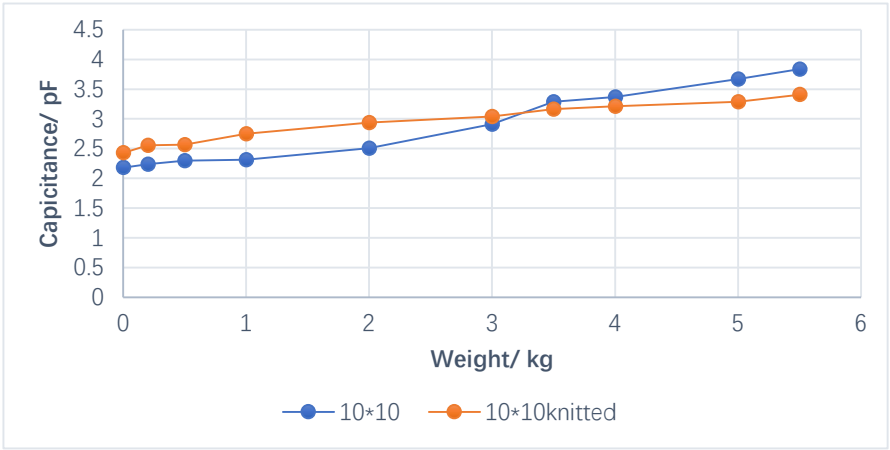
Spacer 7



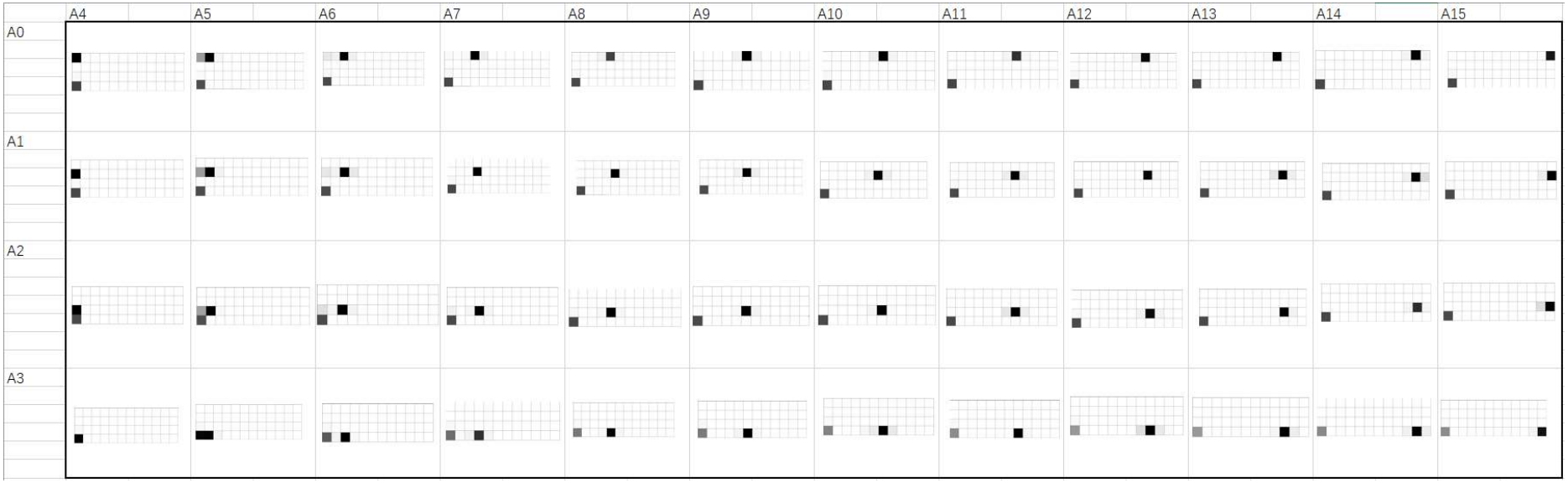
Spacer 8



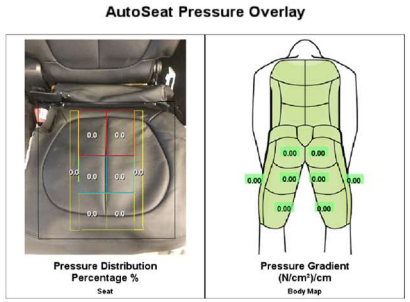
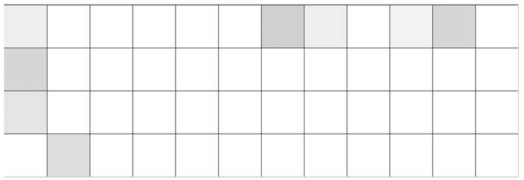
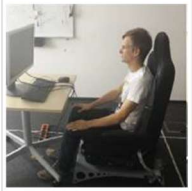
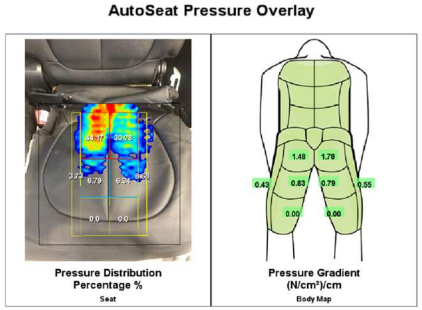
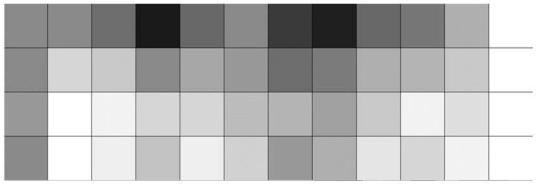
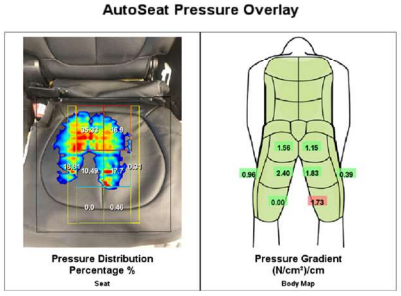
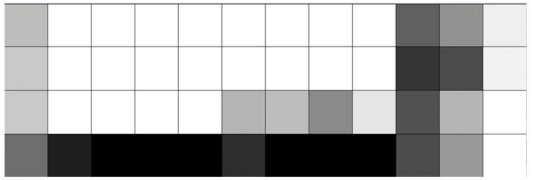
Knitted sample, contact area 10*10

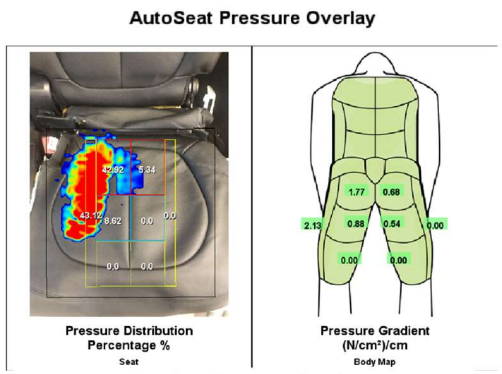
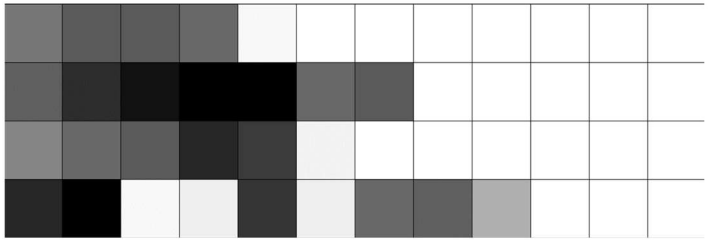
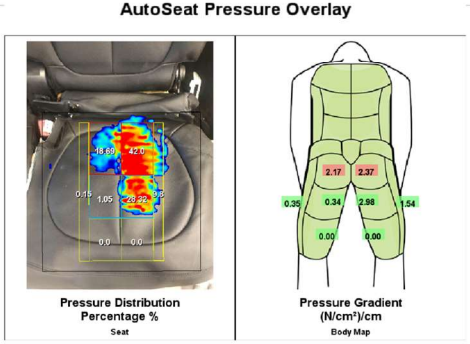
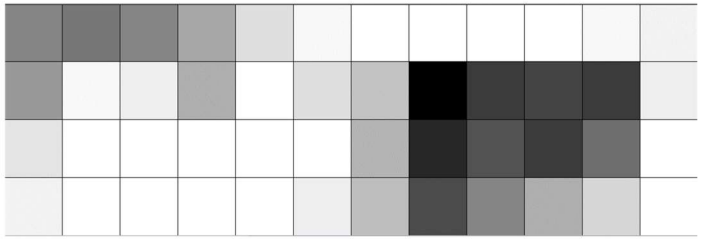
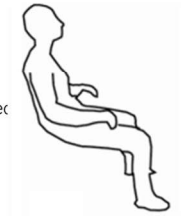
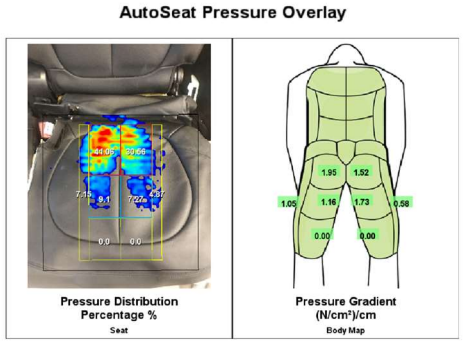
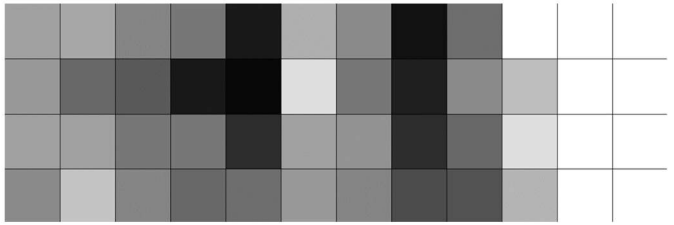
Spacer 2	Spacer 6
	
Spacer 8	
	

Appendix H Testing the color change of each pin in the matrix.



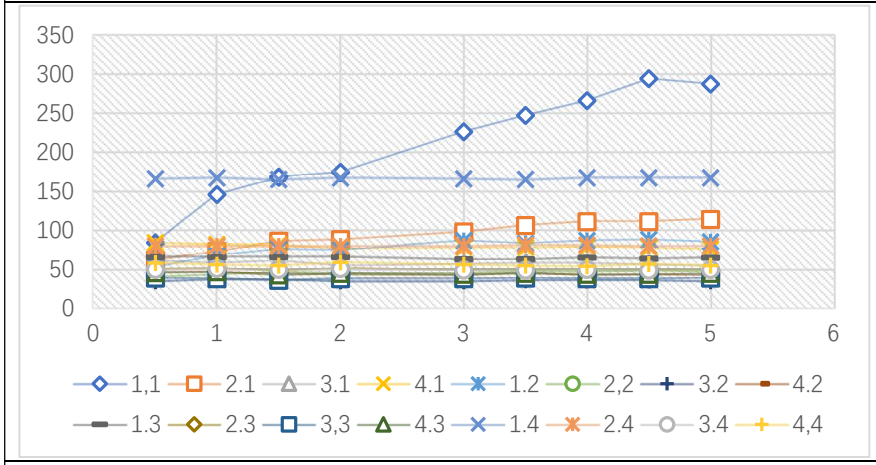
Appendix I Testing the sensor with people- pilot.

start			
sit normal- upright position			
lean front,			

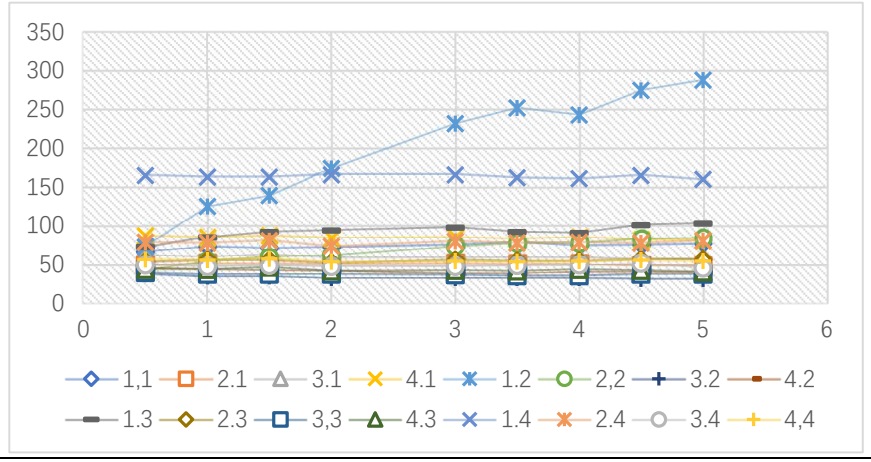
lean right,			
lean left,			
a slightly relaxed			

Appendix J Calibration data of the sample 4*4 30mm. (x- weight/kg, y- capacitance output*100/pF)

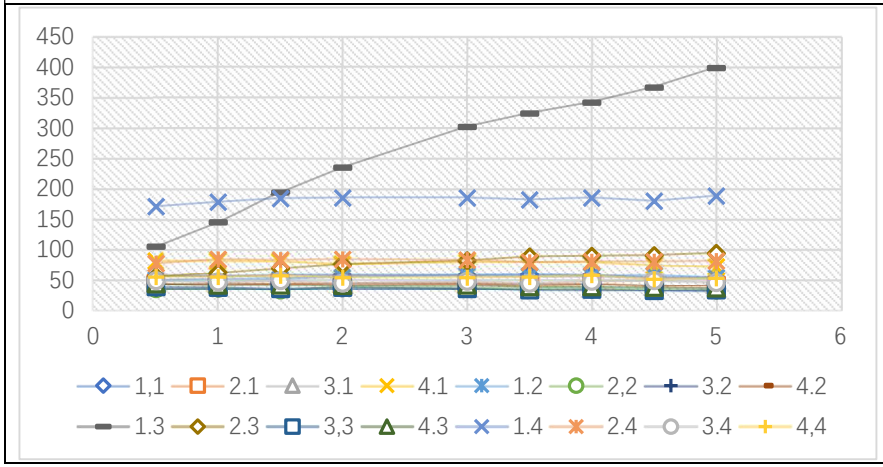
1.1



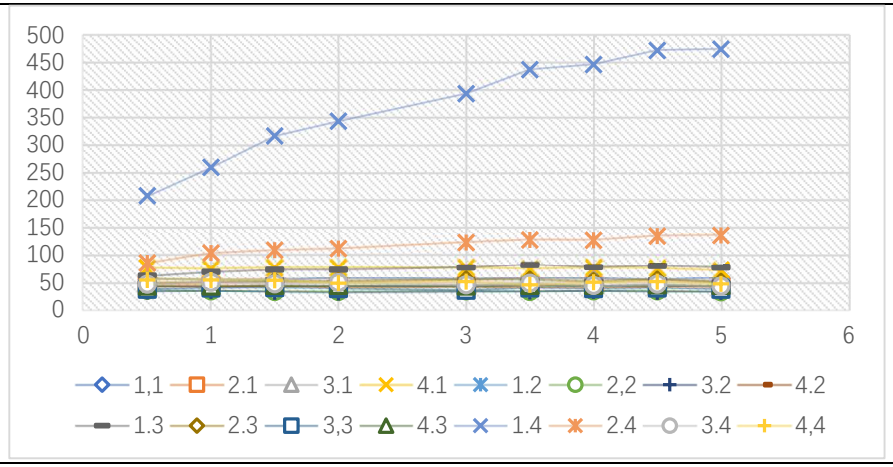
1.2

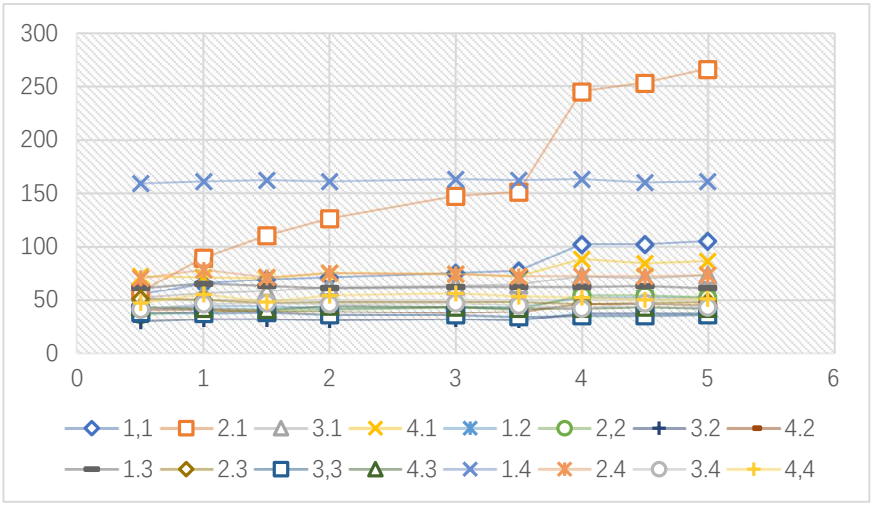
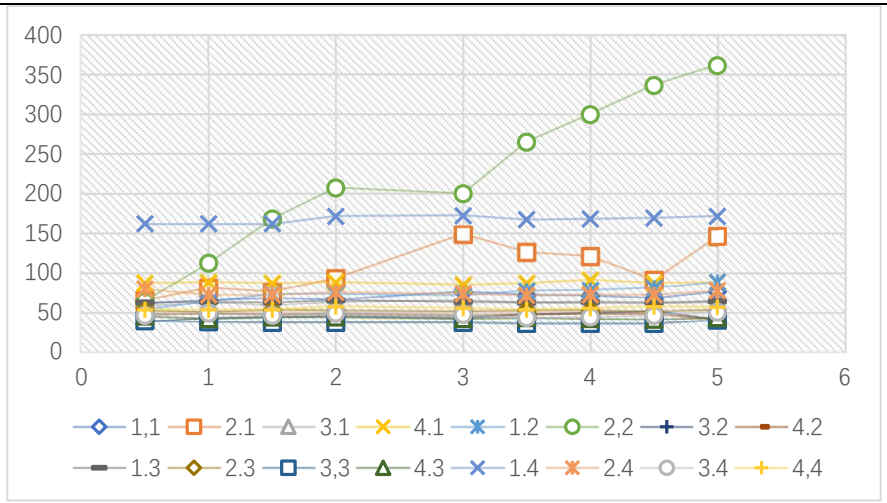
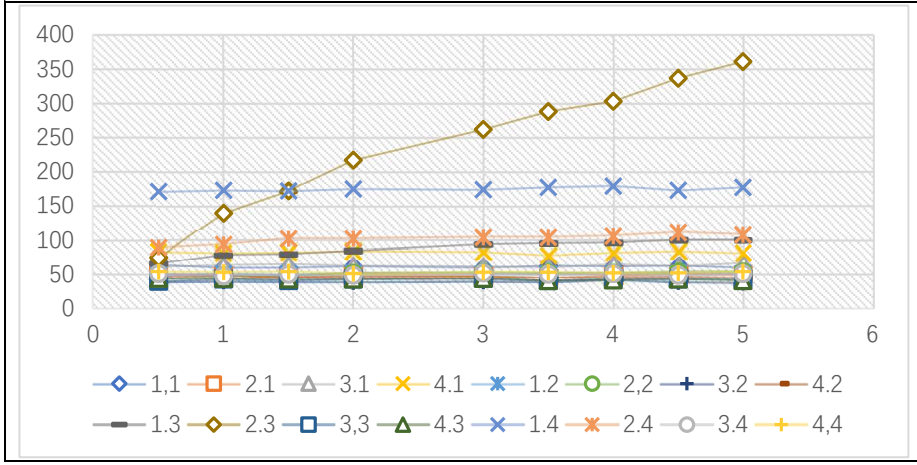
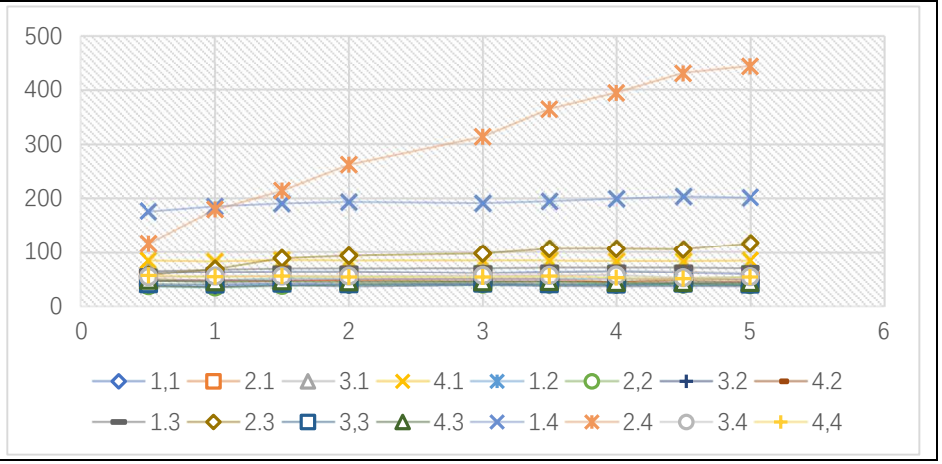


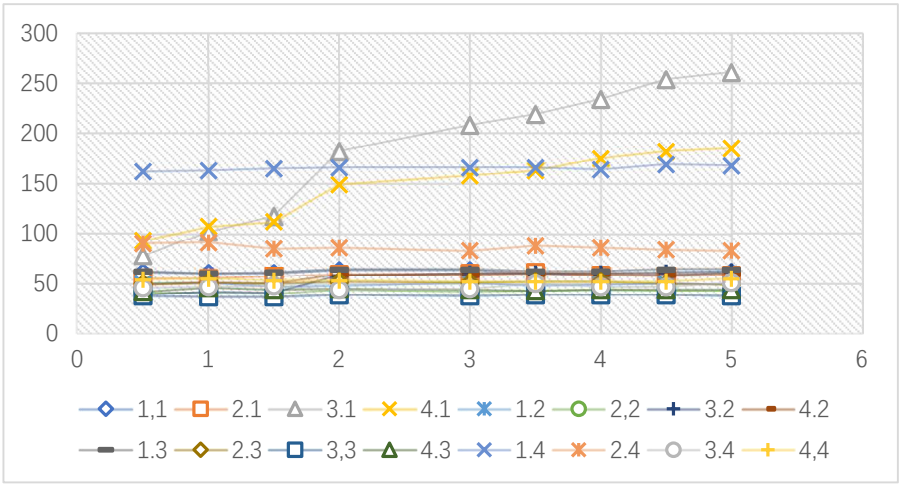
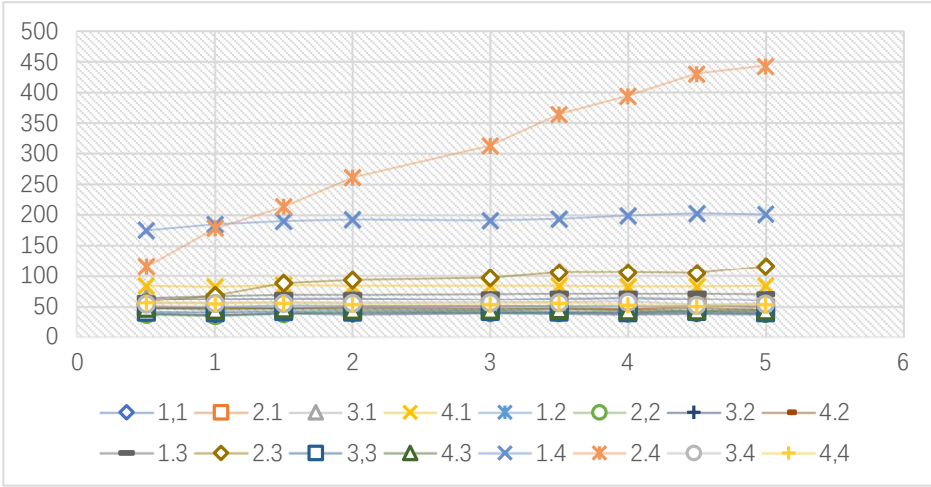
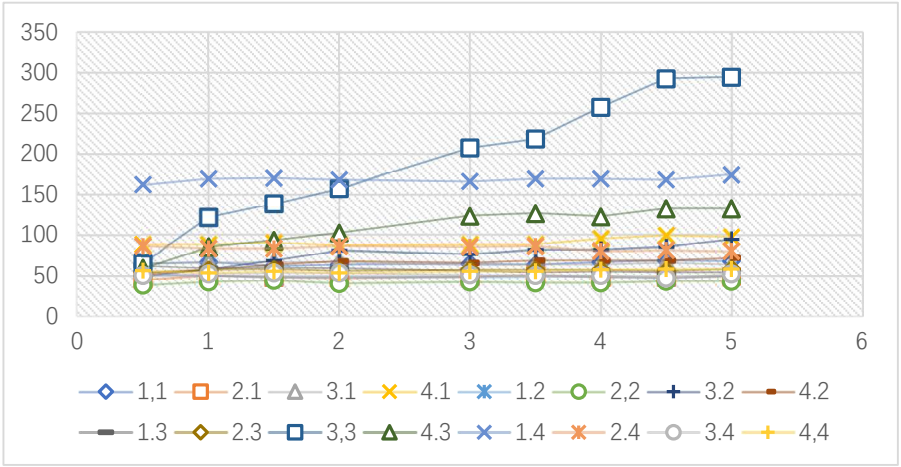
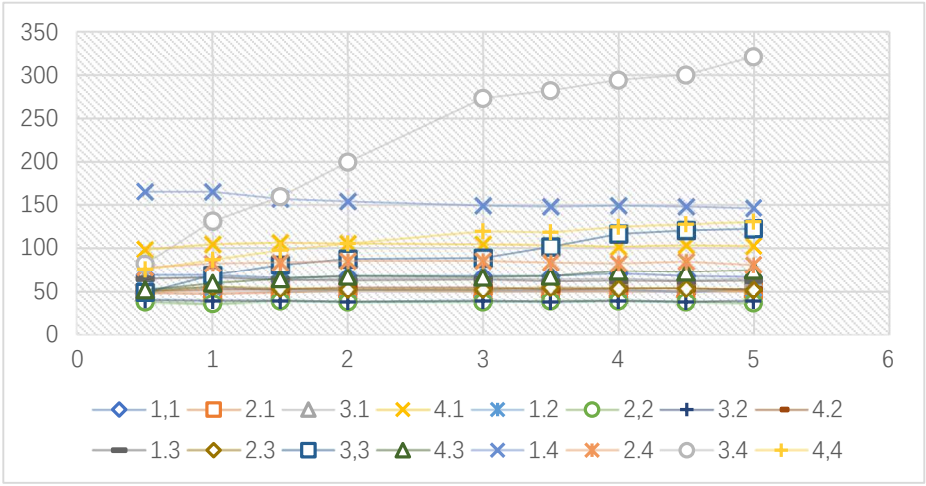
1.3

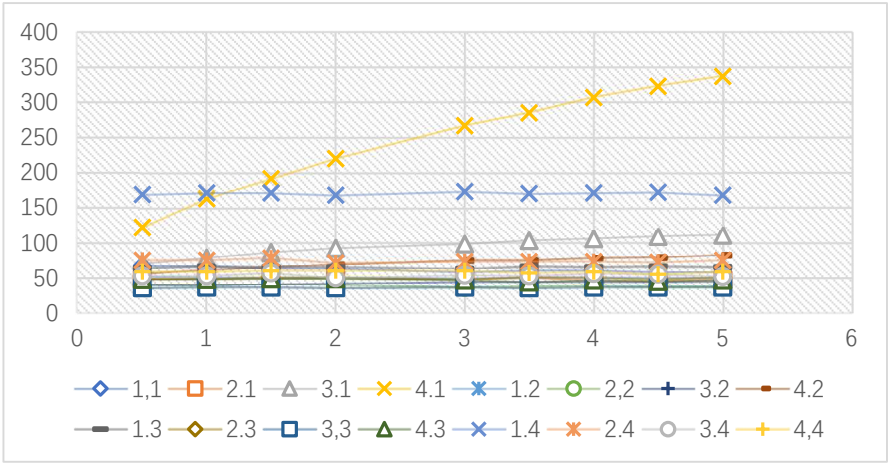
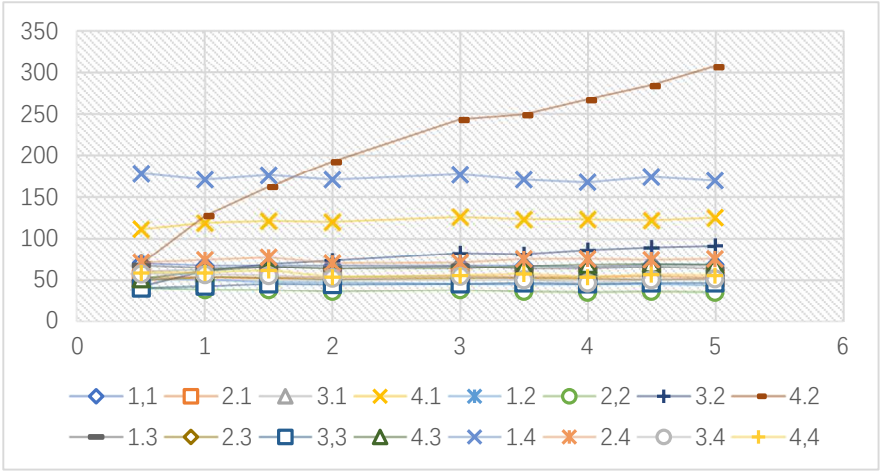
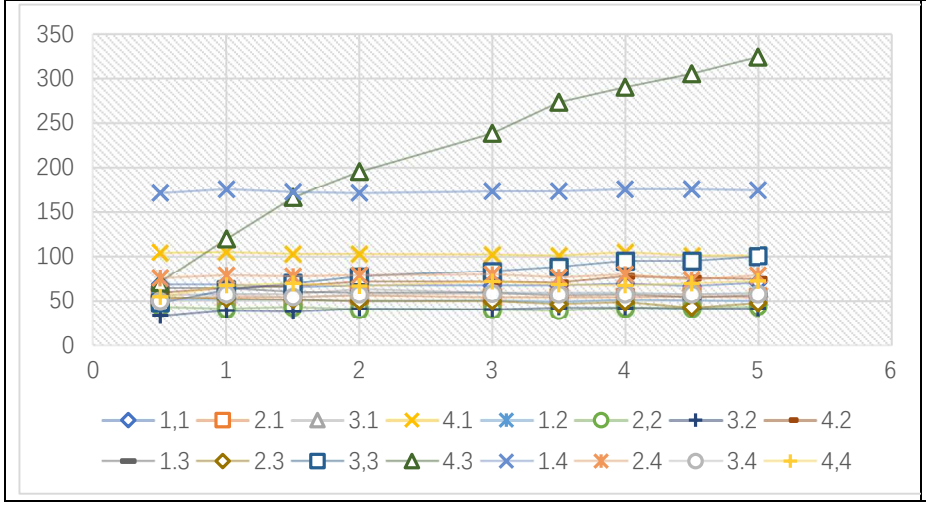
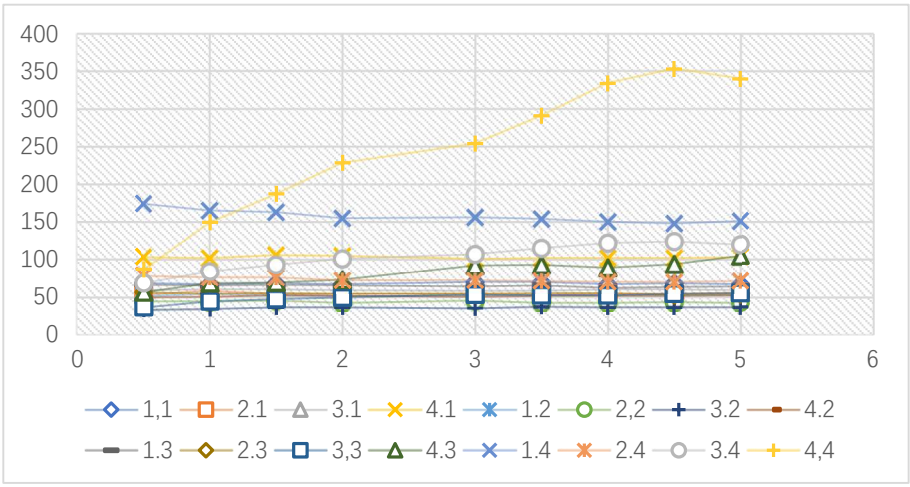


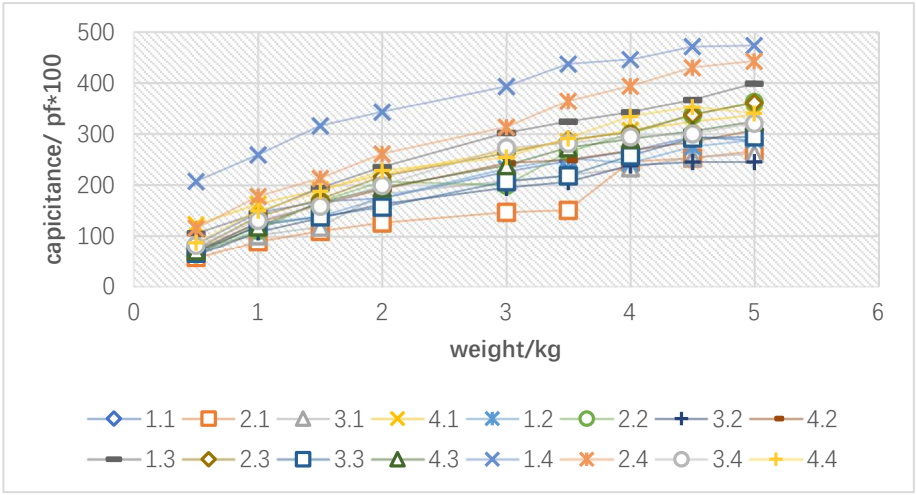
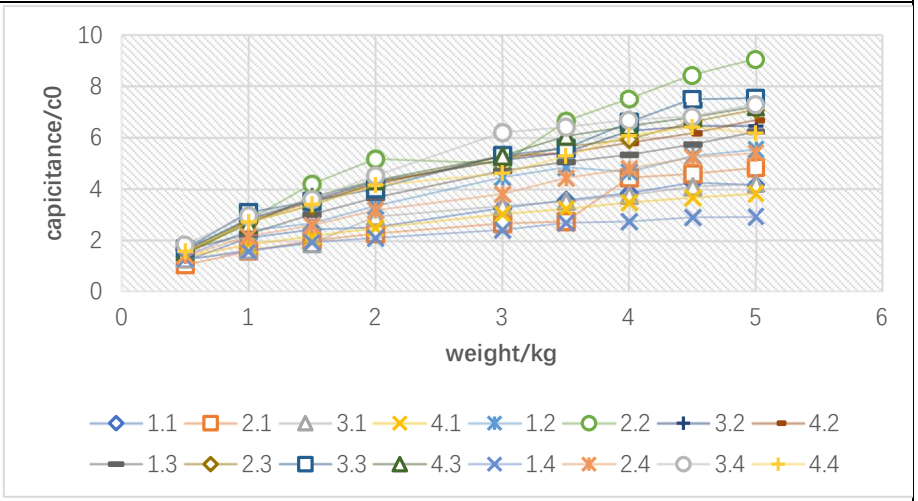
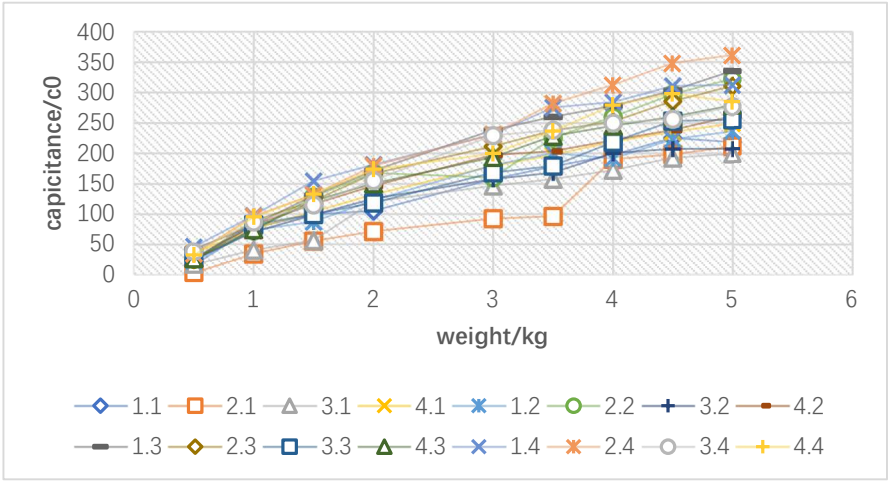
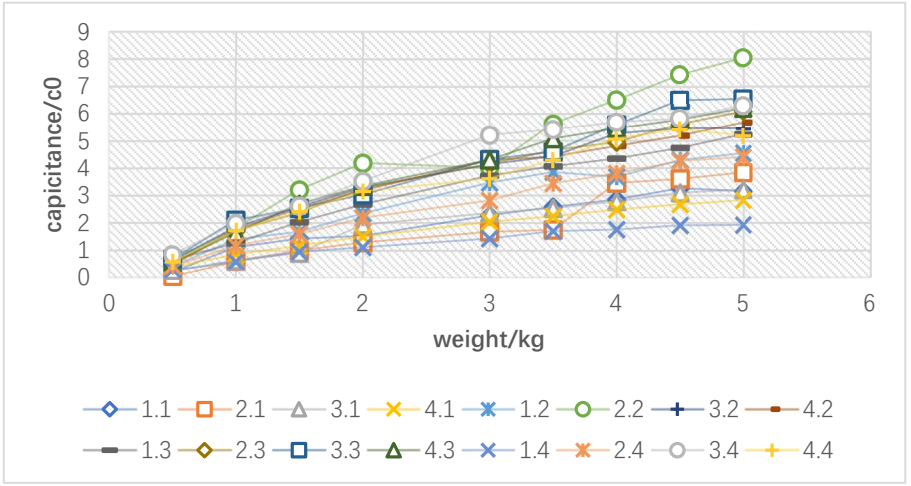
1.4



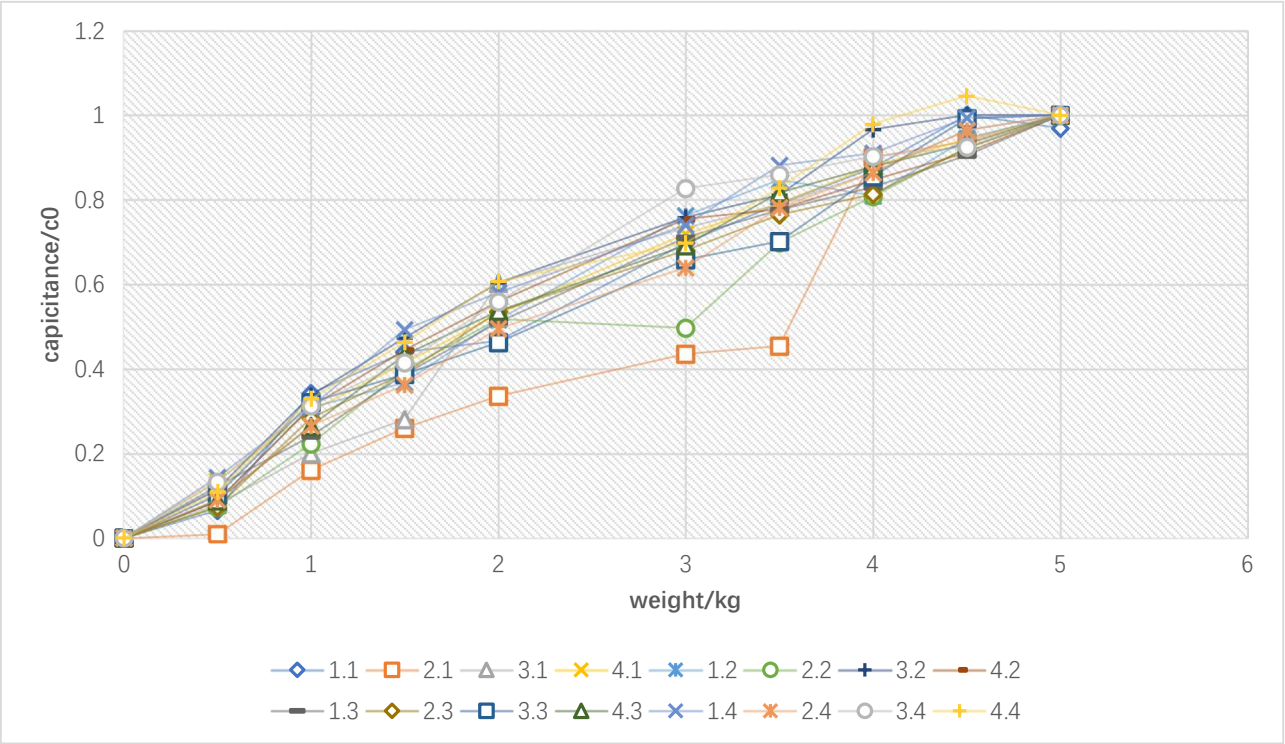
2.1	2.2
 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 400 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4
2.3	2.4
 400 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 500 400 300 200 100 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4

3.1	3.2
 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 500 450 400 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4
3.3	3.4
 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4

4.1	4.2
 400 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4
4.3	**4.4**
 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4	 400 350 300 250 200 150 100 50 0 0 1 2 3 4 5 6 1,1 2.1 3.1 4.1 1.2 2,2 3.2 4.2 1.3 2.3 3,3 4.3 1.4 2.4 3.4 4,4

Raw	Divide
	
Subtract	Subtract and divide
	

Normalize


1.2
1
0.8
0.6
0.4
0.2
0
capicitance/c0
0
1
2
3
4
5
6
weight/kg
1.1
2.1
3.1
4.1
1.2
2.2
3.2
4.2
1.3
2.3
3.3
4.3
1.4
2.4
3.4
4.4

Appendix K Arduino and Processing code

Arduino code

```
// https://www.circuitbasics.
com/how-to-make-an-arduino-capacitance-meter/
const int OUT_PIN1 = A4;
const int OUT_PIN2 = A5;
const int OUT_PIN3 = A6;
const int OUT_PIN4 = A7;
const int OUT_PIN5 = A8;
const int OUT_PIN6 = A9;
const int OUT_PIN7 = A10;
const int OUT_PIN8 = A11;
const int IN_PIN1 = A0;
const int IN_PIN2 = A1;
const int IN_PIN3 = A2;
const int IN_PIN4 = A3;
const float IN_STRAY_CAP_TO_GND = 24.48;
const float IN_CAP_TO_GND = IN_STRAY_CAP_TO_GND;
const float R_PULLUP = 34.8;
const int MAX_ADC_VALUE = 1023;
const int range = 5;
int amin[32];
int amax[32];
void setup()
{
pinMode(OUT_PIN1, OUTPUT);
pinMode(OUT_PIN2, OUTPUT);
pinMode(OUT_PIN3, OUTPUT);
pinMode(OUT_PIN4, OUTPUT);
pinMode(OUT_PIN5, OUTPUT);
pinMode(OUT_PIN6, OUTPUT);
pinMode(OUT_PIN7, OUTPUT);
pinMode(OUT_PIN8, OUTPUT);
pinMode(IN_PIN1, OUTPUT);
pinMode(IN_PIN2, OUTPUT);
pinMode(IN_PIN3, OUTPUT);
pinMode(IN_PIN4, OUTPUT);
Serial.begin(9600);
}
void loop()
{
//calibrate function
while(millis()<600){
Serial.println("calibrate");
int a0min[32];
int a0max[32];
```

```
for (int inPin = A0; inPin <= A3; inPin++) {
for (int outPin = A4; outPin <= A11; outPin++) {
float data = measureCap(inPin, outPin,0);
int MeasurementsToAverage = 100;
for(int i = 0; i < MeasurementsToAverage; ++i)
{
data += measureCap(inPin, outPin, 0);
delay(1);
}
data /= MeasurementsToAverage;
int output = data* 100;
int index =(inPin- A0)*8+ (outPin- A4);
a0min[index]= output;
a0max[index]= output+ range * 60;
Serial.print(a0min[index]);
// Serial.print("(");
// Serial.print(a0max[index]);
// Serial.print(")");
Serial.print(";");
amin[index] = a0min[index];
amax[index] = a0max[index];
}
}
Serial.println();
}
while(millis()>600){
```

```
Serial.println("start");
// int a0max[32];
for (int inPin = A0; inPin <= A3; inPin++) {
for (int outPin = A4; outPin <= A11; outPin++) {
float data = measureCap(inPin, outPin,0);
int MeasurementsToAverage = 50;
for(int i = 0; i < MeasurementsToAverage; ++i)
{
data += measureCap(inPin, outPin, 0);
delay(1);
}
data /= MeasurementsToAverage;
int output = data* 100;
int index =(inPin- A0)*8+ (outPin- A4);
// a0max[index]= output + range * 21+3;
// amax[index] = a0max[index];
// int calibrate = output - amin[index];
// int divide = amax[index]- amin[index];
// int result = calibrate*10000 / divide;
int result = map(output, amin[index], amax[index], 0,
255);
Serial.print(result);
// Serial.print(";");
// Serial.print(output);
// Serial.print("(");
// Serial.print(calibrate);
```

```
// Serial.print(amax[index]);
// Serial.print(";");
// Serial.print(amin[index]);
// Serial.print(";");
// Serial.print(")");
Serial.print("\t");
}
// Serial.println();
}
Serial.println();
}
}
////////////////////////////////////////////////////////
//measure function
float measureCap(int IN_PIN, int OUT_PIN, bool printIt) {
float capacitance;
//check the measured pin
if (printIt) {
Serial.print(F("Measure between "));
Serial.print(IN_PIN);
Serial.print(F(" and "));
Serial.print(OUT_PIN);
}
pinMode(IN_PIN, INPUT);
digitalWrite(OUT_PIN, HIGH);
int val = analogRead(IN_PIN);
digitalWrite(OUT_PIN, LOW);
if (val < 1000)
{
pinMode(IN_PIN, OUTPUT);
digitalWrite(IN_PIN, LOW); // new line
capacitance = (float)val * IN_CAP_TO_GND /
(float)(MAX_ADC_VALUE - val);
if (printIt) {
Serial.print(F(", Capacitance Value = "));
Serial.print(capacitance, 3);
Serial.print(F(" pF ("));
Serial.print(val);
Serial.println(F(") "));
}
}
else
{
Serial.print(F(", Large "));
pinMode(IN_PIN, OUTPUT);
delay(1);
pinMode(OUT_PIN, INPUT_PULLUP);
unsigned long u1 = micros();
unsigned long t;
int digVal;
do
{
```

```
digVal = digitalRead(OUT_PIN);
unsigned long u2 = micros();
t = u2 > u1 ? u2 - u1 : u1 - u2;
} while ((digVal < 1) && (t < 400000L));
pinMode(OUT_PIN, INPUT);
val = analogRead(OUT_PIN);
digitalWrite(IN_PIN, HIGH);
int dischargeTime = (int)(t / 1000L) * 5;
delay(dischargeTime);
pinMode(OUT_PIN, OUTPUT);
digitalWrite(OUT_PIN, LOW);
digitalWrite(IN_PIN, LOW);
capacitance = -(float)t / R_PULLUP
/ log(1.0 - (float)val /
(float)MAX_ADC_VALUE);
Serial.print(F("Capacitance Value = "));
if (capacitance > 1000.0)
{
Serial.print(capacitance / 1000.0, 2);
Serial.print(F(" uF"));
}
else
{
Serial.print(capacitance, 2);
Serial.print(F(" nF"));
}
Serial.print(F(" ("));
Serial.print(digVal == 1 ? F("Normal") : F("HighVal"));
Serial.print(F(", t= "));
Serial.print(t);
Serial.print(F(" us, ADC= "));
Serial.print(val);
Serial.println(F(")"));
}
while (millis() % 1!= 0);
return capacitance;
}
////////////////////////////////////////////////////
```

Processing code

Sensing_matrix4_8_color_change_processing

```
/*
Code based on Tom Igoe’ s Serial Graphing Sketch
>> http://wiki.processing.org/w/Tom_Igoe_Interview
Reads X analog inputs and visualizes them by drawing a grid
using grayscale shading of each square to represent sensor value.
>> http://howtogetwhatyouwant.at/
*/
import processing.serial.*;
Serial myPort; // The serial port
int rows = 8;
int cols = 4;
int maxNumberOfSensors = rows*cols;
float[] sensorValue = new float[maxNumberOfSensors]; // global variable for
storing mapped sensor
values
float[] previousValue = new float[maxNumberOfSensors]; // array of previous
values
int rectSize = 100;
int rectY;
void setup () {
size(800, 400); // set up the window to whatever size you want
rectSize = width/rows;
println((Object[])Serial.list()); // List all the available serial ports
myPort = new Serial(this, "COM5", 9600);
myPort.clear();
myPort.bufferUntil(&apos;\n&apos;); // don’ t generate a serialEvent() until
you get a newline (\n) byte
background(255); // set inital background
smooth(); // turn on antialiasing
rectMode(CORNER);
}
void draw () {
for (int i = 0; i < maxNumberOfSensors; i++) {
fill(sensorValue[i]);
rect(rectSize * (i%rows), rectY, rectSize, rectSize); //top left
if ((i+1) % rows == 0) rectY += rectSize;
}
rectY=0;
}
void serialEvent (Serial myPort) {
String inString = myPort.readStringUntil(&apos;\n&apos;); // get the ASCII
string
println("test");
if (inString != null) { // if it’ s not empty
inString = trim(inString); // trim off any whitespace
int incomingValues[] = int(split(inString, "\t")); // convert to an array of ints
if (incomingValues.length <= maxNumberOfSensors &&
incomingValues.length > 0) {
for (int i = 0; i < incomingValues.length; i++) {
```

```
// map the incoming values (0 to 1023) to an appropriate gray-scale range (0-255):
sensorValue[i] = map(incomingValues[i], 5, 50, 255, 0); // stretch 5×5
println(sensorValue[i]); // print value to see

}
}
}
}
```

Appendix l Raw data for calibration

Raw data 4*4_30

1,1		1				2				3				4			
kg		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	0.5	84	62	61	84	53	41	35	47	66	51	39	46	166	80	50	58
	1	146	73	58	82	68	44	37	47	66	52	38	47	167	80	51	56
	1.5	168	86	61	81	76	47	37	45	66	49	36	43	165	80	50	55
	2	174	88	55	77	75	46	35	44	66	52	38	45	167	80	51	59
	3	226	98	57	78	87	46	35	43	63	50	38	44	166	80	49	56
	3.5	247	106	58	78	83	48	36	46	63	50	39	45	165	81	49	55
	4	266	111	58	79	87	47	36	43	65	50	38	44	167	81	50	54
	4.5	294	111	56	78	88	49	36	44	64	50	38	44	167	80	49	57
	5	287	114	55	76	85	48	35	43	65	50	39	45	167	80	50	55
average			94	58	79	78	46	36	45	64.9	50	38	44.8	166	80	50	56.1

1,2		1				2				3				4			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	0.5	67	50	62	87	73	43	38	46	73	54	40	44	165	79	50	57
	1	74	52	60	85	125	55	35	44	85	56	38	44	163	78	48	56
	1.5	72	52	63	87	139	60	35	43	92	56	38	47	163	81	49	58
	2	73	51	59	84	174	62	33	42	94	53	38	42	166	74	48	54
	3	76	52	59	85	232	74	33	39	98	56	37	43	166	80	48	55
	3.5	79	51	59	83	252	78	33	39	92	55	36	42	162	78	49	54
	4	75	51	59	85	243	78	33	41	91	55	36	44	161	79	50	55
	4.5	76	49	57	82	275	83	32	41	101	57	38	43	165	78	52	56
	5	77	49	57	81	288	84	32	40	103	57	38	41	160	81	46	55
		74.3	51	59	84		69	34	42	92.1	55	38	43.3	163	79	49	55.6

1.3		1				2				3				4			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	0.5	56	45	58	81	50	36	36	43	105	55	39	44	171	77	49	55
	1	56	42	58	81	52	37	35	45	145	62	38	42	178	84	47	55
	1.5	58	45	54	80	52	34	35	44	194	69	36	42	184	83	49	57
	2	58	43	57	76	55	39	35	45	235	76	38	41	185	84	45	54
	3	58	44	56	79	58	38	36	45	302	82	36	42	185	83	48	54
	3.5	59	41	55	79	57	36	34	44	324	88	34	39	182	79	45	55
	4	58	44	55	79	57	36	33	44	342	89	35	39	185	80	48	58
	4.5	54	42	53	74	58	35	33	41	367	90	33	38	180	80	49	51
	5	54	41	52	72	54	34	32	42	399	94	34	37	188	81	46	53
		56.8	43	55	78	54.78	36	34	44		78	36	40.4	182	81	47	54.7

initial value

69	55	62	88
52	40	38	46
64	51	39	45
162	82	44	55

Raw data 4*4_30

1.4

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	55	45	55	76	43	35	33	43	62	48	37	43	207	85	46	54
1	54	45	54	75	42	34	34	42	69	50	39	43	259	103	50	54
1.5	53	43	55	77	42	33	32	44	73	51	40	44	316	108	47	53
2	57	43	55	77	44	33	31	41	73	51	38	44	343	111	49	48
3	55	45	54	77	44	34	32	42	77	54	35	43	393	122	45	51
3.5	56	46	58	75	46	33	33	41	82	54	39	44	437	127	48	45
4	56	44	55	77	43	34	34	40	78	51	38	44	446	126	44	50
4.5	54	43	54	76	45	34	32	42	80	54	39	45	472	134	46	51
5	57	43	52	72	42	32	32	42	77	50	37	44	474	135	43	47
	55.2	44	55	76	43.44	34	33	42	74.6	51	38	43.8		117	46	50.3

2.1

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	55	57	52	72	42	36	30	41	61	51	38	43	159	70	41	47
1	65	89	56	71	44	39	32	41	65	50	37	42	161	78	46	55
1.5	69	110	58	70	44	40	32	39	63	47	38	41	162	71	47	48
2	71	126	62	75	42	41	31	39	61	48	36	44	161	75	46	54
3	75	147	63	74	43	43	32	38	62	48	36	43	163	74	47	56
3.5	77	151	64	72	43	41	31	39	62	48	34	42	162	72	45	53
4	102	245	72	88	52	54	37	46	62	46	35	42	163	72	42	52
4.5	102	253	70	84	52	54	37	46	63	47	35	43	160	72	47	50
5	105	266	73	86	52	52	37	45	61	48	36	42	161	73	43	51
	80.1		63	77	46	44	33	42	62.2	48	36	42.4	161	73	45	51.8

2.2

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	61	65	57	87	53	64	38	47	62	52	39	45	162	79	46	53
1	65	81	62	88	63	112	43	48	63	50	38	42	162	72	49	53
1.5	68	76	58	87	73	168	44	47	62	53	37	44	162	72	46	53
2	66	93	63	88	73	207	45	48	65	52	37	44	171	75	49	57
3	76	149	65	85	71	200	43	46	63	51	37	42	172	73	47	55
3.5	72	126	62	87	77	265	47	47	62	52	36	43	167	71	43	53
4	71	121	61	91	78	300	49	48	63	52	36	42	168	72	44	55
4.5	68	91	60	87	81	337	51	48	62	51	36	41	169	72	46	57
5	76	146	63	88	88	362	41	41	64	53	40	43	171	77	50	56
	69.2	105	61	88	73		45	47	62.9	52	37	42.9	167	74	47	54.7

Raw data 4*4_30

2.3

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	64	51	61	83	50	43	39	47	66	74	40	44	171	89	51	54
1	60	49	64	81	51	48	40	48	79	139	43	44	173	94	48	53
1.5	60	46	65	82	50	49	39	46	80	172	41	43	172	102	50	54
2	62	49	63	84	52	52	39	47	85	217	43	43	175	102	49	51
3	60	48	62	83	51	53	40	47	94	262	44	44	174	104	52	53
3.5	63	45	60	78	51	52	39	45	95	288	41	41	177	104	50	53
4	62	49	65	82	51	52	42	46	96	303	44	42	179	106	51	52
4.5	63	51	62	84	52	54	39	47	100	337	43	43	173	111	49	52
5	60	50	67	81	52	54	38	45	100	361	43	41	177	108	51	54
	61.6	49	63	82	51.11	51	39	46	88.3		42	42.8	175	102	50	52.9

2.4

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	60	50	63	84	48	37	38	46	64	57	41	47	175	115	54	56
1	62	47	63	82	48	35	36	47	67	68	40	44	185	178	55	54
1.5	63	46	62	85	51	38	39	47	69	88	42	46	190	213	55	55
2	63	49	63	84	50	40	37	47	69	93	41	44	193	261	55	53
3	61	50	60	84	50	40	39	46	70	97	42	44	191	313	56	53
3.5	63	50	61	84	50	40	38	46	71	106	41	45	194	364	56	55
4	64	45	65	83	50	40	37	45	71	106	40	43	199	394	57	52
4.5	61	51	63	83	50	40	38	47	71	105	42	43	203	430	52	50
5	59	48	61	84	50	39	37	44	70	116	40	43	201	443	54	53
	61.8	48	62	84	49.67	39	38	46	69.1	93	41	44.3	192		55	53.4

3.1

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	61	55	78	93	50	41	39	49	62	50	38	42	162	90	46	54
1	60	55	102	107	51	41	42	51	60	51	37	46	163	91	47	55
1.5	60	57	118	112	47	40	41	50	61	50	37	44	165	85	48	53
2	63	59	182	149	48	44	58	59	64	52	39	45	166	86	44	53
3	63	60	208	158	51	42	60	59	64	51	38	44	166	83	45	52
3.5	60	61	219	163	48	43	60	60	62	52	39	43	166	88	50	52
4	58	58	234	175	49	44	60	60	62	52	39	44	164	86	47	52
4.5	58	57	254	182	50	43	61	59	64	50	39	44	169	84	47	52
5	61	58	261	185	49	43	62	60	64	49	38	44	168	83	51	55
	60.4	58		147	49.22	42	54	56	62.6	51	38	44	165	86	47	53.1

Raw data 4*4_30

3.2

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	64	46	77	97	49	41	62	60	63	52	41	47	165	90	48	55
1	65	50	79	94	49	49	108	81	62	53	47	50	166	88	49	59
1.5	64	52	87	101	48	51	136	91	63	54	46	49	167	86	48	54
2	62	51	87	98	45	47	163	105	62	52	47	48	166	85	48	53
3	64	53	91	103	45	50	195	116	62	55	48	50	166	88	47	54
3.5	63	54	95	99	45	51	206	118	62	53	47	50	165	85	44	54
4	64	55	96	103	44	48	238	132	62	53	46	50	163	86	47	52
4.5	62	53	100	106	42	49	245	137	59	53	47	51	163	87	46	53
5	62	52	107	108	44	50	245	134	61	53	46	48	161	86	45	53
	63.3	52	91	101	45.67	48		108	61.8	53	46	49.2	165	87	47	54.1

3.3

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	65	45	65	88	51	38	49	52	62	54	65	59	162	86	50	56
1	67	50	66	88	50	42	58	57	59	57	121	85	169	83	52	53
1.5	62	48	67	90	48	44	69	64	60	58	138	93	170	83	53	55
2	64	47	67	87	48	40	81	68	59	56	157	102	168	86	53	53
3	65	49	63	88	48	42	77	66	56	57	207	123	166	85	51	55
3.5	64	51	64	88	49	41	82	69	54	57	218	126	169	86	50	55
4	67	48	64	95	49	41	82	69	55	57	257	122	169	80	50	57
4.5	69	48	66	99	47	43	85	69	54	56	292	132	168	81	47	58
5	68	49	64	97	50	43	94	72	54	58	294	132	174	80	52	58
	65.7	48	65	91	48.89	42	75	65	57	57		108	168	83	51	55.6

3.4

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	68	48	64	98	53	37	39	50	64	50	48	51	165	77	81	75
1	68	47	65	104	54	35	38	52	66	55	68	59	165	82	131	86
1.5	65	49	62	106	51	38	38	52	63	53	80	64	157	83	159	97
2	67	51	64	105	51	37	37	54	62	52	87	67	154	85	199	105
3	67	50	64	104	51	37	38	54	63	52	88	66	149	85	273	119
3.5	67	50	63	103	51	38	37	52	61	54	101	67	148	83	282	118
4	70	50	64	101	52	38	38	53	62	53	116	73	149	82	294	124
4.5	67	50	62	103	49	37	37	53	61	53	120	72	148	84	300	127
5	66	50	64	102	53	36	38	52	62	51	122	74	146	80	321	130
	67.2	49	64	103	51.67	37	38	52	62.7	53	92	65.9	153	82		109

Raw data 4*4_30

4.1

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	67	49	70	122	52	40	40	56	64	48	36	48	169	75	53	59
1	66	49	78	163	51	39	40	61	66	49	37	48	171	75	53	59
1.5	63	51	86	191	50	41	41	65	65	50	37	49	171	78	57	60
2	63	50	92	220	51	40	42	69	65	50	36	49	168	71	50	60
3	58	48	98	267	49	37	44	75	63	48	37	47	173	73	54	60
3.5	60	51	103	285	51	38	44	75	66	51	36	44	170	73	53	57
4	60	46	106	307	51	39	44	78	65	50	37	47	171	73	56	59
4.5	58	46	109	323	50	38	44	79	66	48	37	45	172	72	55	55
5	58	48	111	337	50	38	45	82	65	51	37	47	168	75	52	59
	61.4	49	95		50.56	39	43	71	65	49	37	47.1	170	74	54	58.7

4.2

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	70	52	59	111	51	41	42	69	67	49	40	51	178	71	57	58
1	67	53	62	119	50	38	60	127	64	53	42	60	171	74	56	58
1.5	67	52	65	121	47	38	69	162	65	52	45	65	176	77	55	61
2	67	53	66	120	47	36	73	192	63	50	44	63	171	70	52	53
3	67	54	65	126	45	38	82	243	66	52	45	63	177	71	54	55
3.5	67	53	64	123	44	36	81	249	63	52	46	66	171	75	50	57
4	65	53	65	123	44	35	86	267	63	51	45	68	168	75	46	53
4.5	68	54	66	122	45	36	89	284	65	50	46	69	174	74	50	56
5	68	52	67	125	43	35	91	307	63	51	46	68	170	75	51	55
	67.3	53	64	121	46.22	37	75		64.3	51	44	63.7	173	74	52	56.2

4.3

	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	68	52	56	104	51	43	33	59	64	54	47	70	171	75	49	54
1	68	54	58	105	51	41	39	64	64	52	62	119	175	78	57	67
1.5	65	54	57	103	51	43	38	66	60	51	69	166	172	77	54	69
2	67	56	63	103	49	40	41	71	59	49	77	195	171	78	57	66
3	67	54	59	102	50	40	40	71	59	49	83	238	173	79	58	71
3.5	67	54	59	101	48	39	42	70	56	46	88	273	173	76	57	68
4	69	54	59	105	51	42	42	77	57	48	95	290	175	79	57	67
4.5	66	55	57	101	50	42	41	75	54	42	95	305	175	73	57	69
5	70	54	59	101	49	43	41	74	56	47	100	324	174	78	57	72
	67.4	54	59	103	50	41	40	70	58.8	49	80		173	77	56	67

Raw data 4*4_30

4.4	1				2				3				4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.5	68	53	59	103	51	44	33	49	66	56	36	56	174	78	68	86
1	67	58	60	102	54	44	34	50	65	54	44	68	165	76	84	149
1.5	68	54	60	106	52	45	36	52	66	55	47	69	163	76	93	187
2	67	54	59	105	51	42	36	51	65	54	49	73	155	72	101	228
3	70	54	58	101	52	45	35	50	64	54	53	92	156	72	107	254
3.5	70	53	58	102	52	42	37	51	65	55	52	93	154	71	115	291
4	67	54	60	102	52	42	36	51	62	55	52	89	150	70	122	334
4.5	68	54	60	102	52	43	36	51	63	53	54	94	148	70	124	353
5	67	56	59	103	52	42	36	52	64	54	55	105	151	71	120	340
	68	54	59	103	52	43	35	51	64.4	54	49	82.1	157	73	104	

Sample 1

Thickness			8.5mm					
Times	1		2		3		average	
Data	Displacement	Static force	Displacement	Static force/	Displacement	Static force/N	Displacement	Static force/N
	-16.0857	-0.02	-12.9356	-0.02			14.51069	0.02
	-18.5044	-0.02	-10.5791	-0.0202			14.54171	0.02017
	-40.7867	-0.037	-42.7808	-0.0454			41.78377	0.04135
	-102.903	-0.085	-116.012	-0.0995			109.4575	0.09214
	-173.636	-0.148	-196.343	-0.1628			184.9892	0.15525
	-253.676	-0.218	-283.785	-0.2254			268.7303	0.22191
	-343.37	-0.288	-375.988	-0.279			359.6791	0.28348
	-440.667	-0.348	-469.976	-0.3193			455.3217	0.33357
	-542.862	-0.392	-562.624	-0.3461			552.7429	0.36915
	-646.282	-0.418	-653.396	-0.3614			649.8391	0.38983
	-745.154	-0.427	-742.058	-0.3682			743.6058	0.39773
	-836.849	-0.424	-827.713	-0.3695			832.2809	0.39695
	-916.842	-0.419	-910.177	-0.3702			913.5096	0.39476
	-994.069	-0.419	-992.574	-0.372			993.3214	0.39561
	-1074.1	-0.424	-1074.1	-0.3757			1074.102	0.3998
	-1156.8	-0.43	-1157.14	-0.381			1156.969	0.40556
	-1241.63	-0.436	-1241.45	-0.3858			1241.541	0.41102
	-1327.58	-0.44	-1325.42	-0.3894			1326.499	0.41472
	-1409.79	-0.443	-1408.67	-0.3926			1409.229	0.41771
	-1491.17	-0.448	-1491.44	-0.3963			1491.306	0.42194
	-1574.41	-0.453	-1574.37	-0.4007			1574.387	0.42691
	-1657.44	-0.459	-1657.92	-0.4052			1657.678	0.43207
	-1741.96	-0.464	-1741.74	-0.4093			1741.848	0.4368
	-1825.33	-0.469	-1825.66	-0.4126			1825.492	0.44086
	-1909.37	-0.474	-1909.56	-0.4151			1909.467	0.44433
	-1994.42	-0.477	-1993.1	-0.417			1993.763	0.44698
	-2078.33	-0.479	-2076.1	-0.4191			2077.218	0.44913
	-2162.28	-0.481	-2159.14	-0.4215			2160.709	0.45117
	-2245.54	-0.482	-2242.48	-0.4242			2244.007	0.45321
	-2328.67	-0.484	-2325.45	-0.4272			2327.06	0.45545
	-2412.47	-0.485	-2408.65	-0.4305			2410.56	0.45786
	-2495.48	-0.486	-2492.01	-0.4338			2493.743	0.46012
	-2578.14	-0.488	-2574.83	-0.4374			2576.483	0.46284
	-2660.1	-0.491	-2657.81	-0.4416			2658.954	0.46623
	-2740.91	-0.496	-2740.42	-0.4466			2740.668	0.47106
	-2823.43	-0.502	-2823.99	-0.452			2823.709	0.47684
	-2906.8	-0.508	-2906.85	-0.4572			2906.824	0.48273
	-2990.75	-0.514	-2989.65	-0.4634			2990.2	0.48894
	-3073.96	-0.52	-3072.21	-0.4703			3073.085	0.49534
	-3157.14	-0.526	-3155.55	-0.4779			3156.348	0.50221
	-3240.35	-0.533	-3238.63	-0.4855			3239.492	0.50912
	-3323.35	-0.539	-3322.01	-0.4933			3322.684	0.51619
	-3406.21	-0.546	-3404.93	-0.5014			3405.566	0.52364
	-3489.27	-0.553	-3488.12	-0.5098			3488.692	0.53141
	-3571.54	-0.561	-3571.43	-0.5184			3571.483	0.53959
	-3654.14	-0.569	-3654.59	-0.5269			3654.367	0.54816
	-3736.88	-0.579	-3737.86	-0.5358			3737.367	0.55723
	-3819.94	-0.588	-3820.62	-0.545			3820.28	0.56667
	-3902.81	-0.598	-3903.33	-0.555			3903.072	0.57663

Appendix M Spacer data in Test 1.5

-3985.16	-0.609	-3986.3	-0.5657
-4067.91	-0.62	-4068.94	-0.577
-4151.09	-0.632	-4151.73	-0.5893
-4233.34	-0.644	-4234.26	-0.6024
-4315.7	-0.658	-4316.89	-0.6166
-4398.16	-0.672	-4399.79	-0.6315
-4480.77	-0.686	-4482.12	-0.6473
-4563.05	-0.702	-4564.44	-0.6645
-4645.49	-0.719	-4647.12	-0.6829
-4728.29	-0.736	-4729.86	-0.702
-4810.03	-0.754	-4812.58	-0.722
-4891.71	-0.774	-4895.04	-0.743
-4973.97	-0.795	-4977.2	-0.7653
-5056.41	-0.817	-5059.19	-0.7893
-5137.84	-0.84	-5140.5	-0.8155
-5218.45	-0.866	-5221.4	-0.8448
-5298.87	-0.894	-5303.03	-0.8768
-5379.19	-0.924	-5383.93	-0.9115
-5459.59	-0.958	-5464.51	-0.9497
-5539.84	-0.994	-5544.99	-0.9918
-5619.41	-1.034	-5625.19	-1.0377
-5698.29	-1.077	-5704.44	-1.0885
-5776.63	-1.125	-5783.17	-1.1451
-5854.66	-1.177	-5862.08	-1.2078
-5931.85	-1.235	-5940.49	-1.2767
-6008.41	-1.299	-6018.39	-1.3525
-6084.47	-1.369	-6095.55	-1.436
-6159.63	-1.447	-6171.58	-1.5285
-6234.06	-1.532	-6246.47	-1.6316
-6307.66	-1.627	-6320.23	-1.7467
-6380.02	-1.73	-6392.68	-1.8754
-6451.11	-1.845	-6463.59	-2.0196
-6520.41	-1.972	-6532.7	-2.1817
-6587.79	-2.112	-6600.22	-2.3639
-6653.48	-2.269	-6666.02	-2.5683
-6717.35	-2.442	-6729.73	-2.7975
-6779.26	-2.635	-6791.18	-3.0545
-6839.57	-2.848	-6850.57	-3.3422
-6898.35	-3.084	-6908.27	-3.6631
-6955.31	-3.343	-6963.55	-4.0198
-7010.25	-3.628	-7016.53	-4.4156
-7062.9	-3.94	-7067.21	-4.8535
-7113.48	-4.282	-7115.32	-5.3369
-7161.92	-4.655	-7160.95	-5.8691
-7208.23	-5.061	-7204.38	-6.4532
-7252.32	-5.504	-7245.88	-7.0921
-7294.3	-5.984	-7285.61	-7.7882
-7334.19	-6.503	-7323.55	-8.544
-7372.24	-7.063	-7359.79	-9.3616
-7408.55	-7.667	-7394.52	-10.243
		-7427.77	-11.191

3985.731	0.58729
4068.425	0.59868
4151.409	0.61064
4233.797	0.62331
4316.293	0.63708
4398.977	0.65156
4481.444	0.66688
4563.747	0.68334
4646.305	0.70084
4729.078	0.71905
4811.305	0.73813
4893.374	0.7585
4975.584	0.78021
5057.799	0.8032
5139.169	0.82784
5219.928	0.85516
5300.95	0.88518
5381.564	0.91794
5462.051	0.95382
5542.416	0.99302
5622.302	1.03573
5701.366	1.08274
5779.902	1.13494
5858.368	1.19254
5936.169	1.25589
6013.398	1.32573
6090.012	1.40268
6165.606	1.48771
6240.266	1.58198
6313.945	1.68661
6386.348	1.80286
6457.353	1.93227
6526.553	2.07667
6594.006	2.23811
6659.75	2.41851
6723.54	2.61991
6785.218	2.84473
6845.072	3.09525
6903.312	3.37342
6959.43	3.68137
7013.389	4.02161
7065.054	4.39667
7114.396	4.80921
7161.433	5.26191
7206.308	5.75736
7249.101	6.29792
7289.956	6.88588
7328.869	7.52338
7366.015	8.21256
7401.536	8.95528
7427.774	11.1913

Sample 2

5.5mm

1		2		3		average		1
Displacement	Static force/N	Displacement	Static force/N	Displacement	Static force/N	Displacement	Static force/N	Displacement
-21.5043	-0.02	-14.8054	-0.02	-15.7751	-0.02	17.36158	0.019998	-8.17597
-23.6374	-0.02024	-18.7485	-0.02008	-18.5331	-0.02009	20.30631	0.020139	-9.91568
-46.4026	-0.03698	-39.2709	-0.03749	-40.292	-0.03756	41.98852	0.03734	-27.8091
-99.2635	-0.08186	-96.0798	-0.08815	-99.614	-0.08685	98.3191	0.085617	-59.8793
-159.237	-0.14662	-159.443	-0.16005	-165.139	-0.1557	161.273	0.154125	-90.5597
-230.091	-0.22484	-237.657	-0.24499	-245.387	-0.23578	237.7117	0.235203	-127.089
-320.585	-0.3058	-344.847	-0.32224	-355.583	-0.30661	340.3383	0.311547	-171.589
-467.655	-0.36514	-493.178	-0.35774	-496.14	-0.33594	485.6578	0.352942	-221.048
-632.209	-0.35324	-598.453	-0.34084	-583.166	-0.32885	604.6093	0.340977	-273.873
-660.143	-0.34402	-649.825	-0.34005	-650.505	-0.33585	653.4912	0.33997	-331.887
-734.84	-0.36107	-736.503	-0.3518	-739.907	-0.34583	737.0831	0.352902	-398.736
-837.882	-0.37012	-822.691	-0.35867	-826.044	-0.35105	828.8721	0.359944	-477.499
-921.172	-0.37131	-907.807	-0.36407	-910.491	-0.35442	913.1566	0.363269	-571.883
-1003.67	-0.37442	-993.463	-0.36729	-995.799	-0.35688	997.6447	0.366197	-691.886
-1091.05	-0.37574	-1076.52	-0.3694	-1079.09	-0.35757	1082.223	0.367573	-846.891
-1175.92	-0.37485	-1159.04	-0.37242	-1161.19	-0.35958	1165.381	0.368953	-1150.68
-1257.84	-0.37398	-1242.54	-0.37545	-1244.09	-0.36211	1248.157	0.370511	-1813.84
-1337.53	-0.375	-1324.91	-0.37901	-1327.46	-0.3649	1329.966	0.372971	-1788.09
-1417.41	-0.37894	-1407.88	-0.38325	-1408.8	-0.36829	1411.361	0.376827	-1711.76
-1500.95	-0.384	-1491.04	-0.38769	-1490.54	-0.37388	1494.175	0.381857	-1608.47
-1583.78	-0.38905	-1573.78	-0.39241	-1574.79	-0.37962	1577.449	0.387027	-1563.5
-1665.52	-0.39477	-1656.84	-0.39767	-1657.45	-0.38499	1659.939	0.392475	-1571.06
-1747.04	-0.40195	-1740.23	-0.40286	-1739.74	-0.39152	1742.334	0.398777	-1607.42
-1829.61	-0.41006	-1822.16	-0.40863	-1823.58	-0.39813	1825.115	0.405605	-1663.52
-1913.32	-0.41833	-1904.42	-0.41589	-1906.52	-0.40461	1908.086	0.412944	-1720.82
-1996.56	-0.42636	-1986.83	-0.42363	-1988.49	-0.41201	1990.628	0.420664	-1767.21
-2079.25	-0.43472	-2067.99	-0.43324	-2070.24	-0.42069	2072.493	0.42955	-1801.23
-2161.29	-0.44376	-2150.81	-0.44401	-2152.45	-0.43086	2154.849	0.439543	-1828.5
-2243.33	-0.45386	-2233.29	-0.45527	-2235.44	-0.44157	2237.354	0.450233	-1854.56
-2326.7	-0.46442	-2315.68	-0.46749	-2317.66	-0.45296	2320.015	0.461623	-1879.41
-2409.09	-0.47511	-2398.91	-0.48019	-2400.07	-0.46534	2402.693	0.47355	-1901.67
-2490.75	-0.48692	-2481.63	-0.49306	-2482.22	-0.4787	2484.866	0.486225	
-2571.68	-0.50025	-2563.6	-0.50703	-2564.29	-0.49316	2566.522	0.500148	
-2653.78	-0.51497	-2645.1	-0.52236	-2645.93	-0.50906	2648.268	0.515461	
-2736	-0.53045	-2726.22	-0.53969	-2727.99	-0.52634	2730.072	0.53216	
-2817.33	-0.54709	-2807.76	-0.55885	-2808.99	-0.54521	2811.359	0.550383	
-2898.12	-0.56547	-2889.21	-0.57971	-2889.43	-0.56665	2892.254	0.570608	
-2978.7	-0.5857	-2969.61	-0.60281	-2970.64	-0.59048	2972.982	0.592995	
-3058.12	-0.6085	-3049.6	-0.62886	-3051.27	-0.61643	3052.998	0.617929	
-3137.75	-0.63412	-3129.49	-0.65806	-3130.97	-0.64539	3132.736	0.645858	
-3217.14	-0.66251	-3208.57	-0.69086	-3209.91	-0.67808	3211.872	0.677151	
-3296.05	-0.69404	-3287.4	-0.72776	-3288.16	-0.71526	3290.535	0.712351	
-3374.1	-0.72906	-3365.82	-0.76903	-3366.15	-0.75737	3368.688	0.75182	
-3450.66	-0.76859	-3442.82	-0.8155	-3443.46	-0.80472	3445.648	0.796271	
-3526.26	-0.8135	-3518.82	-0.86839	-3519.55	-0.85822	3521.541	0.846704	
-3600.85	-0.86448	-3594.14	-0.92848	-3593.8	-0.9194	3596.264	0.90412	
-3673.91	-0.92246	-3668.2	-0.99654	-3666.77	-0.98971	3669.629	0.969571	
-3745.01	-0.98879	-3740.17	-1.07419	-3738.34	-1.07034	3741.171	1.044439	
-3814.68	-1.0647	-3810.09	-1.1635	-3807.5	-1.16309	3810.761	1.130432	

-3882.62	-1.15135	-3878.13	-1.26612	-3874.29	-1.27024	3878.349	1.229235
-3949.05	-1.24998	-3943.62	-1.38425	-3938.81	-1.39397	3943.828	1.342733
-4013.64	-1.36174	-4006.54	-1.52018	-4000.5	-1.53661	4006.891	1.472843
-4075.54	-1.48833	-4065.8	-1.67686	-4059.09	-1.70101	4066.811	1.622065
-4134.49	-1.63187	-4121.93	-1.85758	-4114.65	-1.89005	4123.688	1.793165
-4190.12	-1.79467	-4175.52	-2.06491	-4167.19	-2.10658	4177.607	1.988718
-4242.49	-1.97919	-4226.32	-2.30131	-4216.64	-2.35345	4228.485	2.211317
-4291.74	-2.18779	-4274.24	-2.56946	-4262.99	-2.6336	4276.321	2.463618
-4338.05	-2.4227	-4319.32	-2.87203	-4306.26	-2.94992	4321.208	2.748218
-4381.24	-2.68617	-4361.57	-3.21168	-4346.52	-3.3053	4363.111	3.067716
-4421.74	-2.98035	-4401.13	-3.59098	-4384	-3.70246	4402.289	3.424596
-4459.77	-3.30714	-4438.14	-4.01239	-4418.73	-4.14401	4438.877	3.82118
-4495.61	-3.66828	-4472.82	-4.4782	-4451.01	-4.6324	4473.149	4.259628
-4529.38	-4.06532	-4505.16	-4.99055	-4481.27	-5.16977	4505.268	4.741877

Sample 7

3.0mm

l		2		3		average		1	
Static force/N	Displacement	Static force/N	Displacement	Static force/N	Displacement	Static force/N	Displacement	Static force/N
-0.02	-7.25663	-0.02	-6.92753	-0.02	7.453376	0.019998	-7.94862	-0.02
-0.02021	-8.89351	-0.02022	-7.79506	-0.02024	8.868081	0.020225	-9.76304	-0.02021
-0.0566	-24.6976	-0.06217	-27.0394	-0.06595	26.51538	0.061573	-33.3098	-0.05434
-0.18323	-57.3395	-0.20938	-65.0642	-0.2228	60.76102	0.205138	-91.013	-0.15143
-0.40661	-95.7131	-0.45587	-106.961	-0.4861	97.74452	0.449525	-151.501	-0.29161
-0.72204	-138.81	-0.79052	-154.594	-0.84377	140.1644	0.785445	-209.67	-0.4771
-1.11586	-187.767	-1.20248	-208.398	-1.28103	189.2514	1.199787	-270.27	-0.70757
-1.5759	-242.031	-1.67982	-268.16	-1.78317	243.7465	1.679629	-338.971	-0.97424
-2.09506	-301.615	-2.2123	-335.563	-2.3343	303.6837	2.213886	-420.102	-1.25734
-2.66595	-370.009	-2.78547	-413.912	-2.91241	371.9361	2.787942	-512.562	-1.53243
-3.27587	-450.865	-3.37771	-510.837	-3.48277	453.4793	3.378785	-606.364	-1.78693
-3.90537	-551.274	-3.95627	-627.606	-3.99568	552.1262	3.95244	-690.984	-2.03198
-4.52953	-675.462	-4.47638	-765.503	-4.41059	670.9492	4.472165	-775.895	-2.27433
-5.11326	-828.908	-4.88679	-961.25	-4.6377	827.348	4.879247	-852.946	-2.5189
-5.59805	-1196.03	-5.0353	-1227.74	-4.43715	1090.22	5.023499	-918.503	-2.78678
-5.89313	-1665.66	-4.23257	-1232.85	-4.13618	1349.73	4.753963	-980.96	-3.09184
-5.25257	-1548.68	-3.35991	-1234.48	-4.0403	1532.335	4.217591	-1043.05	-3.4353
-4.29311	-1417.6	-2.94865	-1295.33	-4.11311	1500.341	3.784957	-1092.91	-3.82869
-3.57391	-1379.33	-2.88563	-1473.35	-4.02147	1521.482	3.493672	-1134.18	-4.29309
-3.18613	-1395.55	-3.01097	-1483.5	-3.93744	1495.839	3.378179	-1167.99	-4.84305
-3.09421	-1443.63	-3.24163	-1527.71	-4.00907	1511.614	3.448301	-1195.34	-5.49157
-3.18404	-1514.7	-3.51938	-1615.82	-4.08964	1567.195	3.597684	-1218.59	-6.24874
-3.38521	-1591.62	-3.8136	-1648.72	-4.24096	1615.92	3.813255	-1239.58	-7.12008
-3.65228	-1659.08	-4.12814	-1687.19	-4.50654	1669.929	4.095652	-1258.81	-8.10949
-3.96511	-1707.73	-4.49452	-1721.89	-4.88438	1716.812	4.448005		
-4.3352	-1744.09	-4.94656	-1751.95	-5.38628	1754.416	4.889346		
-4.78464	-1773.74	-5.50321	-1780.24	-6.02019	1785.067	5.436013		
-5.33206	-1800.89	-6.17388	-1807.07	-6.78927	1812.153	6.098403		
-5.98373	-1826.03	-6.96243	-1830.89	-7.6987	1837.16	6.881618		
-6.74152	-1847.21	-7.87507	-1850.13	-8.7583	1858.918	7.791629		
-7.60872	-1864.88	-8.91997	-1866.45	-9.97721	1877.666	8.835302		

Sample 8

2.0mm

2		3		average	
Displacement	Static force/N	Displacement	Static force/N	Displacement	Static force/N
-7.04862	-0.02	-7.80126	-0.02	7.599503	0.019998
-8.72056	-0.02023	-8.91303	-0.02023	9.132209	0.020223
-33.0227	-0.05807	-33.0904	-0.05797	33.14095	0.056794
-94.0611	-0.16252	-94.9177	-0.15944	93.33059	0.157798
-156.194	-0.30995	-158.675	-0.30216	155.4568	0.301241
-217.344	-0.50414	-220.274	-0.48636	215.7624	0.4892
-281.306	-0.74289	-282.421	-0.71629	277.9993	0.722249
-354.223	-1.01394	-356.08	-0.98004	349.7579	0.989404
-438.846	-1.29566	-441.69	-1.25056	433.5461	1.267854
-528.989	-1.56604	-534.325	-1.50811	525.2922	1.535528
-614.817	-1.826	-622.691	-1.74915	614.6238	1.787356
-699.592	-2.08231	-705.417	-1.98587	698.6644	2.033386
-784.367	-2.33587	-785.377	-2.22745	781.8798	2.279218
-860.856	-2.59282	-859.01	-2.48014	857.6038	2.530619
-927.044	-2.87619	-922.914	-2.76479	922.8204	2.809254
-990.848	-3.19932	-985.591	-3.08983	985.7996	3.126997
-1047.2	-3.56882	-1040.17	-3.46535	1043.475	3.489821
-1092.77	-4.00689	-1087.01	-3.90777	1090.895	3.914447
-1130.97	-4.53282	-1124.96	-4.43442	1130.039	4.420111
-1162.26	-5.16136	-1155.81	-5.06215	1162.019	5.022187
-1188.6	-5.9047	-1181.38	-5.80357	1188.438	5.733282
-1210.99	-6.7729	-1204.06	-6.66729	1211.216	6.562978
-1231.9	-7.77126	-1224.88	-7.65781	1232.118	7.516384
-1251.33	-8.90279	-1244.34	-8.77849	1251.492	8.596923

Appendix N Cost estimation

Total production price: € 153.55 Product series: 2000 pieces

Material	Bruto amount/product	Unit	Price/unit	Total price:	
Silver coated yarn	100	m	€ 0.35	€ 35.00	
Foam	0.2	m2	€ 2.50	€ 0.50	
Stainless steel yarn	20	m	€ 0.29	€ 5.80	
Sewing yarn	25	m	€ 0.00	€ 0.11	
Machine knitting yarn	0.5	kg	€ 12.00	€ 6.00	
Space knit fabric	0.5	m2	€ 4.00	€ 2.00	
				€ -	
				Material costs/ product:	**€ 49.41**

Material	Processing	Capacity (units/hour)	Machining hours	Hourly rate	Machine costs
Silver coated yarn	Machine knitting	100	20.00	€ 60.00	€ 1,200.00
Machine knitting yarn	Machine knitting	100	20.00	€ 10.00	€ 200.00
Sewing yarn	Machine sewing	50	40.00	€ 30.00	€ 1,200.00
Stainless steel yarn	Machine sewing	50	40.00	€ 10.00	€ 400.00
Space knit fabric	Machine sewing	50	40.00	€ 10.00	€ 400.00
Foam	Cutting	500	4.00	€ 15.00	€ 60.00
				Total processing costs:	€ 3,460.00

Machines	Person/machine	Working hours	Hourly rate	Labour costs
Machine knitting	1	20.00	€ 25.74	€ 514.80
Machine sewing	1	20.00	€ 25.74	€ 514.80
Cut	1	40.00	€ 25.74	€ 1,029.60
Soldering	1	40.00	€ 25.74	€ 1,029.60
Cutting	1	4.00	€ 25.74	€ 102.96
Assembling	1	1.00	€ 25.74	€ 25.74
			Total Labour costs	€ 3,191.76
			Total processing costs	€ 6,651.76
			Processing costs/ product:	**€ 3.33**

Investments	Costs		Lifecycle		Price/product
Change in the seat	€	1,000.00	5000	€	0.20

Total investment/ product:	€	0.20

General allowances	
Failure factor	1%

Added costs:	€	0.53

TOTAL PRODUCTION COSTS

€ 53.47

Bought components	Price/component		Components/product	Total amount	Price/ product	
Ribbon cable	€	2.37	1	2000	€	2.37
PCB board	€	4.95	1	2000	€	4.95
				0	€	-
				Total price/product	€	7.32

Bought electronics	Price/component	Components/product	Total amount	Price/ product
	€20.00	2	4000	€40.00
	*estimated			
			Total price/ product	€40.00
		More realistic aproximation	**(Total price *50%)**	**€20.00**

TOTAL BOUGHT COSTS

€ 27.32

Assembly	Capacity pieces/hour	Machine hours	Hourly rate		Total costs	
Assemblystation	4	500	€	43.33	€	21,665.00
Hand assemblystation	4	500	€	2.50	€	1,250.00
Packaging	20	100	€	2.00	€	200.00
				Total machinecosts	€	**23,115.00**

Assembly	Person/machine	Labour time	Hourly rate	Labour costs

Assemblystation	1	500	€	25.00	€	12,500.00
Setting up assemblystation	1	10	€	30.00	€	300.00
Hand assembly	1	500	€	18.00	€	9,000.00
Packaging	1	100	€	18.00	€	1,800.00
				Total labour costs	€	**23,600.00**

Assembly costs/ product		
	€	23.36
Total production costs	€	153.6

https://www.wearic.com/product/silver-yarn-20m/

https://www.schuimwinkel.nl/dun-polyether-sg25-aan-de-meter-5mm-x-115-cm-breed.html?source=googlebase&gclid=Cj0KCQjwvvj5BRDkARIsAGD9vlITv5ZlcwiZ3Cg9yBbpZKa91NCP65AqrZfkvTIaKyqL4sEsoTNL62gaAm1eEALw_wcB

https://www.kiwi-electronics.nl/stainless-thin-conductive-thread-2-ply-23-meter?gclid=Cj0KCQjwvvj5BRDkARIsAGD9vlLcvkJ44RDogWTYQ6K4Yi0u7qQsz5eo_9jUKshO_zrBhABmfU-fCzUaAqxsEALw_wcB

https://www.alwaysknittingandsewing.co.uk/products/rainbow-craft-cotton-fabric-green-blenders-by-the-half-metre-or-15-piece-bundle-39911-p?variant=20623972630590&currency=GBP&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&utm_campaign=gs-2019-10-25&utm_source=google&utm_medium=smart_campaign&gclid=Cj0KCQjwvvj5BRDkARIsAGD9vlKNLlbS9oOtSrs9TnvgdW9tK641LSVmT8M2niqMQWC5ExlvSGCst9saAti5EALw_wcB

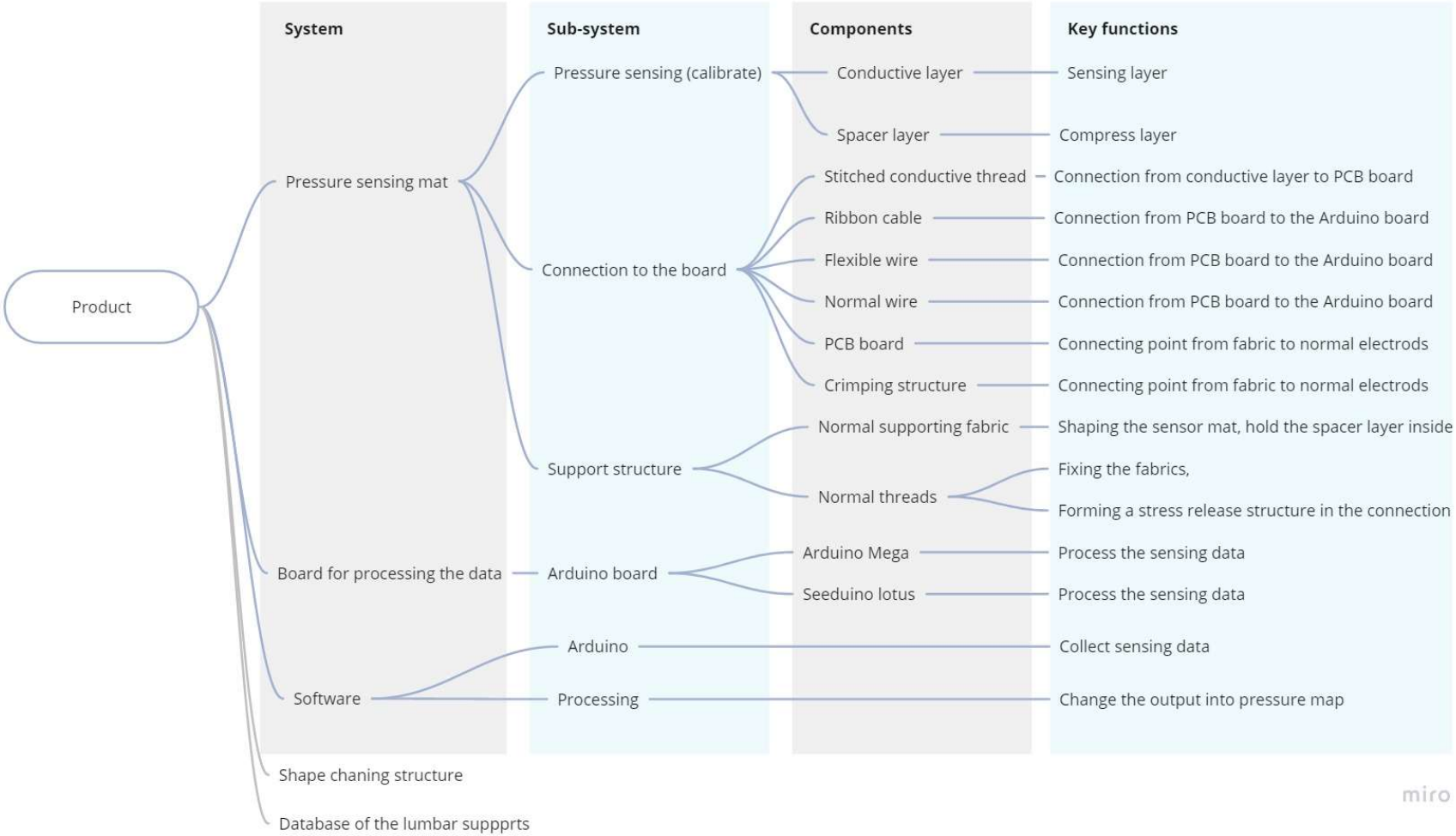
https://www.kiwi-electronics.nl/40-pins-regenboog-gpio-kabel-10cm?search=ribbo&description=true

https://www.kiwi-electronics.nl/prototyping-board-9x15cm-2-54mm-pitch?search=pcb%20board&description=true

Appendix O Stitches used in the knitting samples

Stitches	Width /cm
220	31
300	48
80	17
228	32 (width)
287	20 (height)
278	40 (width)
307	24 (height)

Appendix P System and subsystem.



Appendix Q Consent form

Consent Form for

Testing the fabric pressure sensing mat with people on car seats.

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated 26/06/2020, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves a video- recorded testing process. The video will be destroyed after 3 months of the test.	○	○
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: The test is conducted during COVID-19 period. There is only one participant at one time. Everything used for testing are cleaned with alcohol.	○	○
Use of the information in the study		
I understand that information I provide will be used for thesis and final presentation of this	○	○

graduation project. The face in the video will be blurred.

I understand that personal information collected about me that can identify me, such as my gender, age, weight, height, will not be shared beyond the study team. ○ ○

Future use and reuse of the information by others

I give permission for the gender, age, weight, height that I provide to be archived in the thesis so it can be used for future research and learning. The data will be anonymised. ○ ○

Signatures

_____ _____ _____

Name of participant Signature
Date

For participants unable to sign their name, mark the box instead of sign

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__Yixuan Ma_____ _____ _____

Researcher name Signature Date

Study contact details for further information:

Yixuan Ma*, +31617163428, Y.Ma-7@student.tudelft.nl*

Information sheet for

Testing the fabric pressure sensing mat with people on car seats.

This research is part of the Industrial Design Education, as part of University of Delft, Netherlands. Whenever you have questions about this research you can contact:

Yixuan Ma, *+31617163428, Y.Ma-7@student.tudelft.nl*

Dear Mr/Mrs,
We would like to invite you to take part in this research, executed by: Yixuan Ma

- Purpose of the research
  Research question:
  1. What is the most suitable knitting pattern for the fabric pressure sensor on the lumbar support
  2. If the fabric pressure sensor can detect pressure distribution with different seating posture compare to XSENSOR.

- Benefits and risks of participating
  The test is conducted during COVID-19 period. There is only one participant at one time. Everything used for testing are cleaned with alcohol.

- Procedures for withdrawal from the study
  The test will take around 30 min.
  You will be asked to position the lumbar support in the comfort height to start the test. The height of the lumbar support when seating will be measured by a ruler on the chair.

The test starts and you will be asked to perform 5 postures: sit normal- upright, lean front, lean right, lean left, a slightly relaxed seating. Each posture will last for 1 minute. The pressure distribution map and capacitance change will be monitored by laptop. In each round, each position beside the home position has been taken once. After finishing the test of all postures with all samples, you will be asked to fill in your basic data including your weight, height, and age. A video will be taken during the test. The information will be used for thesis and final presentation of this graduation project. The face in the video will be blurred.

You have the right to request access to and rectification or erasure of personal data.
Your participation is voluntary, whenever there will be questions asked you do not want to answer, please mention so. At all times you can mention that you want to stop. Cancelling has no consequences.

- Usage of the data

Your gender, age, weight, height will be archived in the thesis so it can be used for future research and learning. The data will be anonymised. The video will be destroyed after 3 months of the test.

Please sign the consent form when you decide to cooperate with this study, at the start of the research.

Thanks for taking part in this research!

Reference

Acar, G., Ozturk, O., Golparvar, A. J., Elboshra, T. A., Böhringer, K., & Yapici, M. K. (2019). Wearable and Flexible Textile Electrodes for Biopotential Signal Monitoring: A review. *Electronics, 8*(5). doi:10.3390/electronics8050479

Achilli, A., Pani, D., & Bonfiglio, A. (2017). *Characterization of Screen-Printed Textile Electrodes Based on Conductive Polymer for ECG Acquisition*. Paper presented at the 2017 Computing in Cardiology Conference (CinC).

Brady, S., Diamond, D., & Lau, K.-T. (2005). Inherently conducting polymer modified polyurethane smart foam for pressure sensing. *Sensors and Actuators A: Physical, 119*(2), 398-404. doi:10.1016/j.sna.2004.10.020

Cao, R., Pu, X., Du, X., Yang, W., Wang, J., Guo, H., . . . Wang, Z. L. (2018). Screen-Printed Washable Electronic Textiles as Self-Powered Touch/Gesture Tribo-Sensors for Intelligent Human-Machine Interaction. *ACS Nano, 12*(6), 5190-5196. doi:10.1021/acsnano.8b02477

Castano, L. M., & Flatau, A. B. (2014). Smart fabric sensors and e-textile technologies: a review. *Smart Materials and Structures, 23*(5). doi:10.1088/0964-1726/23/5/053001

E. R. Post, M. O., P.R. Russo, N. Gershenfeld (2000). E-broidery: Design and fabrication of textile- based computing. *IBM SYSTEMS JOURNAL, 39*.

Hughes-Riley, T., Oliveira, C., Morris, R., & Dias, T. (2019). The characterization of a pressure sensor constructed from a knitted spacer structure. *Digital Medicine, 5*(1). doi:10.4103/digm.digm_17_18

Kim, M., Kim, H., Park, J., Jee, K.-K., Lim, J. A., & Park, M.-C. (2018). Real-time sitting posture correction system based on highly durable and washable electronic textile pressure sensors. *Sensors and Actuators A: Physical, 269*, 394-400. doi:10.1016/j.sna.2017.11.054

M. Sergio, N. M., M. Tartagni, R. Canegallo. (2002). A Textile Based Capacitive Pressure Sensor.

Maurin Donneaud, C. H., Paul Strohmeier. (2017). Designing a Multi-Touch eTextile for Music Performances. *NIME 17*.

Meyer, J., Arnrich, B., Schumm, J., & Troster, G. (2010). Design and Modeling of a Textile Pressure Sensor for Sitting Posture Classification. *IEEE Sensors Journal, 10*(8), 1391-1398. doi:10.1109/jsen.2009.2037330

Pizarro, F., Villavicencio, P., Yunge, D., Rodriguez, M., Hermosilla, G., & Leiva, A. (2018). Easy-to-Build Textile Pressure Sensor. *Sensors (Basel), 18*(4). doi:10.3390/s18041190

Poupyrev, I., Gong, N.-W., Fukuhara, S., Karagozler, M. E., Schwesig, C., & Robinson, K. E. (2016). *Project Jacquard*. Paper presented at the Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.

Pourjafarian, N., Withana, A., Paradiso, J. A., & Steimle, J. (2019). *Multi-Touch Kit*. Paper presented at the Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology.

Qi, K., Wang, H., You, X., Tao, X., Li, M., Zhou, Y., . . . Cui, S. (2020). Core-sheath nanofiber yarn for textile pressure sensor with high pressure sensitivity and spatial tactile acuity. *J Colloid Interface Sci, 561*, 93-103. doi:10.1016/j.jcis.2019.11.059

Roh, J.-S. (2013). Textile touch sensors for wearable and ubiquitous interfaces. *Textile Research Journal, 84*(7), 739-750. doi:10.1177/0040517513503733

Seiichi Takamatsu, T. K., Nobuhisa Shibayama, Koji Miyake, Toshihiro Itoh. (2011). Meter-scale surface capacitive type of touch sensors fabricated by weaving conductive-polymer-coated fibers. *EDA Publishing*.

Sergio, M., Manaresi, N., Campi, F., Canegallo, R., Tartagni, M., & Guerrieri, R. (2003). A dynamically reconfigurable monolithic cmos pressure sensor for smart fabric. *IEEE Journal of Solid-State Circuits, 38*(6), 966-975. doi:10.1109/jssc.2003.811977

Shimojo, M., Namiki, A., Ishikawa, M., Makino, R., & Mabuchi, K. (2004). A Tactile Sensor Sheet Using Pressure Conductive Rubber With Electrical-Wires Stitched Method. *IEEE Sensors Journal, 4*(5), 589-596. doi:10.1109/jsen.2004.833152

Takamatsu, S., Kobayashi, T., Shibayama, N., Miyake, K., & Itoh, T. (2012). Fabric pressure sensor array fabricated with die-coating and weaving techniques. *Sensors and Actuators A: Physical, 184*, 57-63. doi:10.1016/j.sna.2012.06.031

Thomas Holleczek, A. R., Holger Harms, Gerhard Tröster. (2010). Textile pressure sensors for sports application. *IEEE SENSORS 2010 Conference*.

Vu, C. C., & Kim, J. (2020). Simultaneous Sensing of Touch and Pressure by Using Highly Elastic e-Fabrics. *Applied Sciences, 10*(3). doi:10.3390/app10030989

Wang, D. (2015). Capacitive Sensing: Ins and Outs of Active Shielding. *Texas Instruments I*.

Wang, Y., Hua, T., Zhu, B., Li, Q., Yi, W., & Tao, X. (2011). Novel fabric pressure sensors: design, fabrication, and characterization. *Smart Materials and Structures, 20*(6). doi:10.1088/0964-1726/20/6/065015

Wu, R., Ma, L., Patil, A., Hou, C., Zhu, S., Fan, X., . . . Liu, X. Y. (2019). All-Textile Electronic Skin Enabled by Highly Elastic Spacer Fabric and Conductive Fibers. *ACS Appl Mater Interfaces, 11*(36), 33336-33346. doi:10.1021/acsami.9b10928

Xu, X., Luo, M., He, P., Guo, X., & Yang, J. (2019). Screen printed graphene electrodes on textile for wearable electrocardiogram monitoring. *Applied Physics A, 125*(10). doi:10.1007/s00339-019-3006-x

Zhou, Z., Li, Y., Cheng, J., Chen, S., Hu, R., Yan, X., . . . Li, L. (2018). Supersensitive all-fabric pressure sensors using printed textile electrode arrays for human motion monitoring and human–machine interaction. *Journal of Materials Chemistry C, 6*(48), 13120-13127. doi:10.1039/c8tc02716a