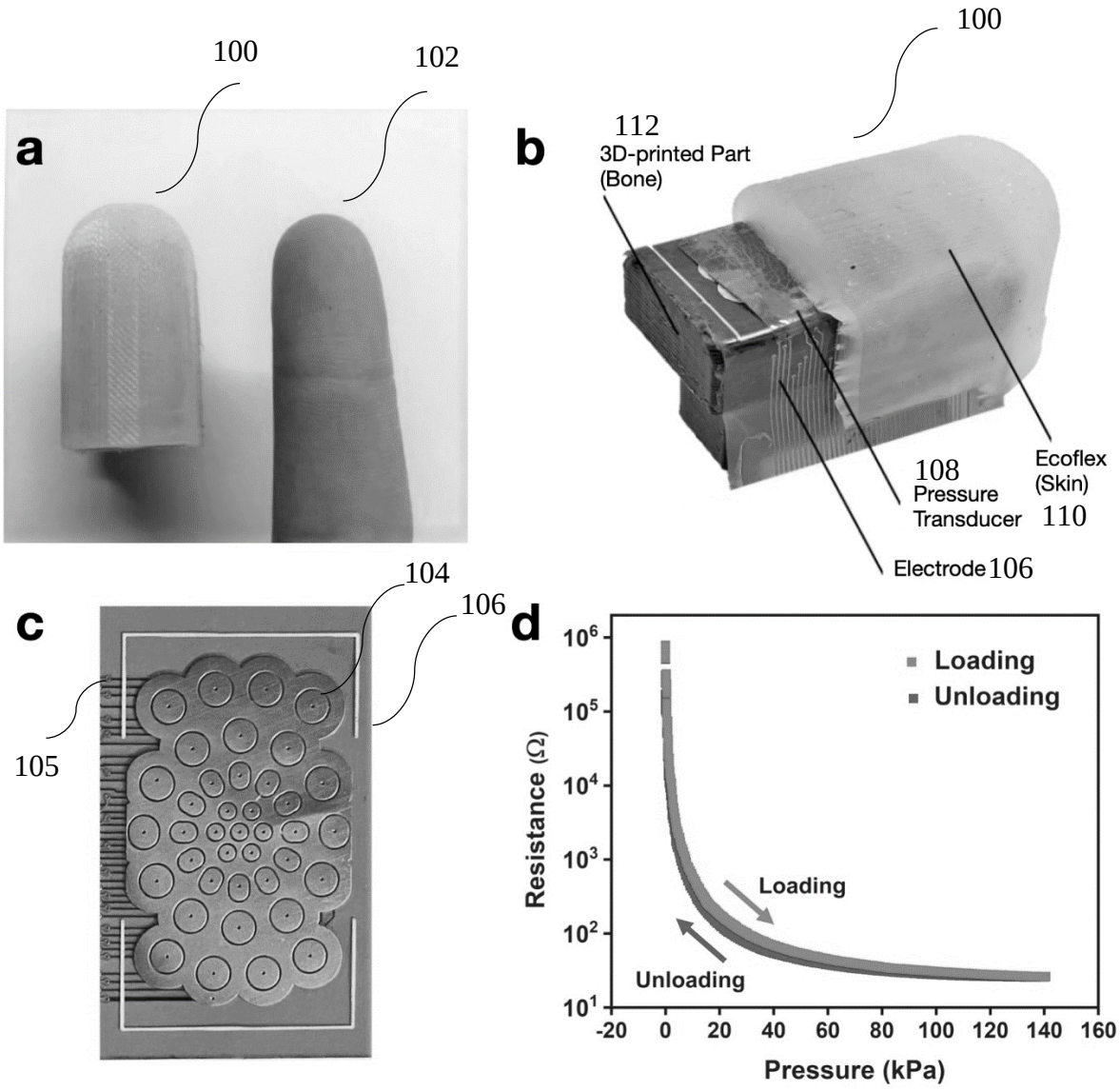
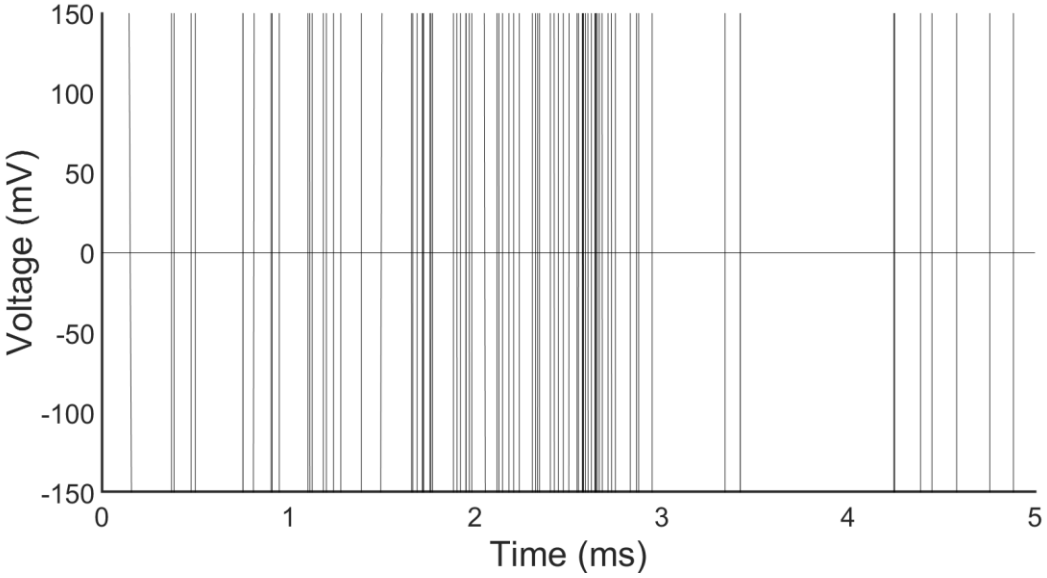

a
100
102
b
100
112
3D-printed Part
(Bone)
108
Pressure
Transducer
Ecoflex
(Skin)
110
Electrode 106
c
104
106
105
d
Loading
Unloading
Resistance (Ω)
10^6
10^5
10^4
10^3
10^2
10^1
Loading
Unloading
-20
0
20
40
60
80
100
120
140
160
Pressure (kPa)

Figure 1

e



f

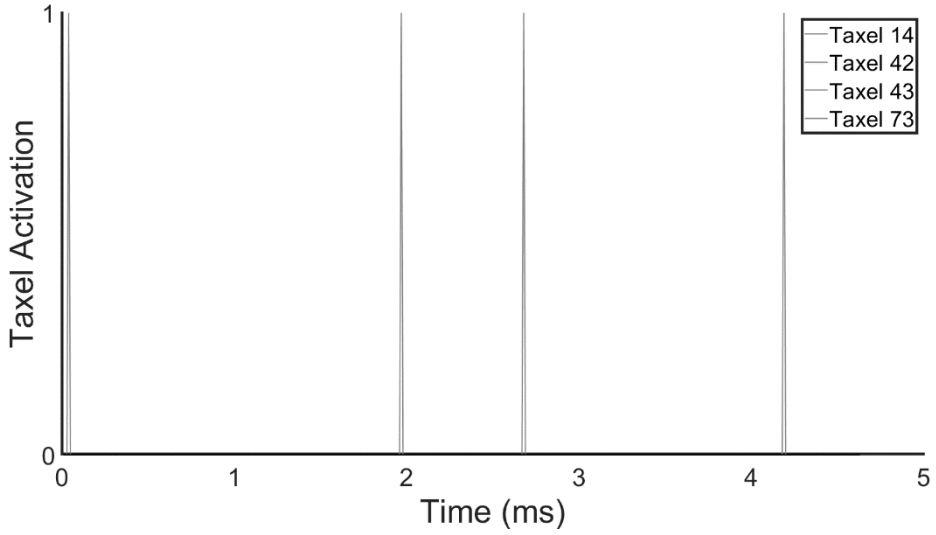


Figure 1 (continued)

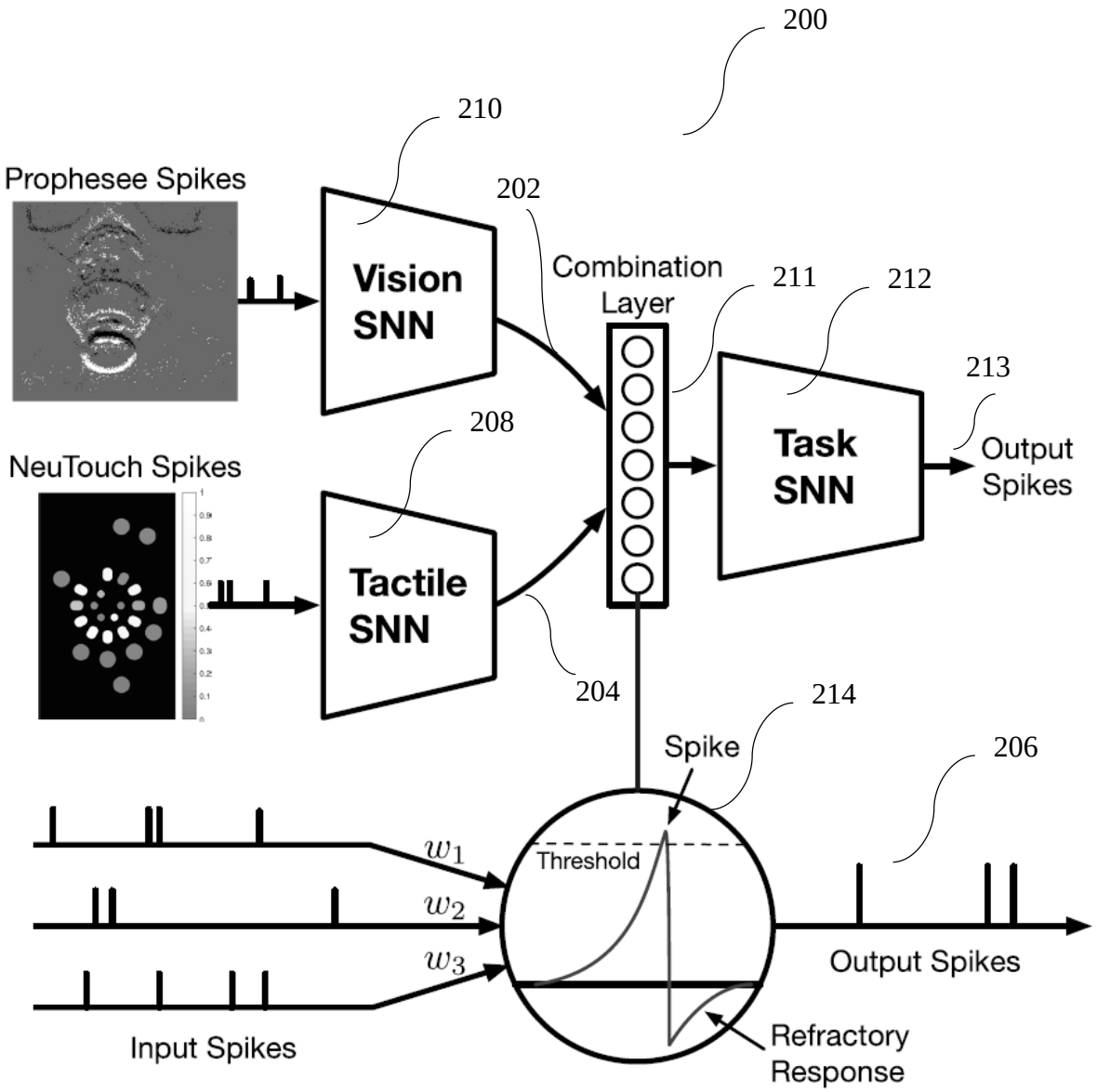

200
210
Prophesee Spikes
202
Vision SNN
Combination Layer
211
212
213
Task SNN
Output Spikes
208
NeuTouch Spikes
Tactile SNN
204
214
Spike
206
w_1
w_2
w_3
Threshold
Output Spikes
Input Spikes
Refractory Response

Figure 2

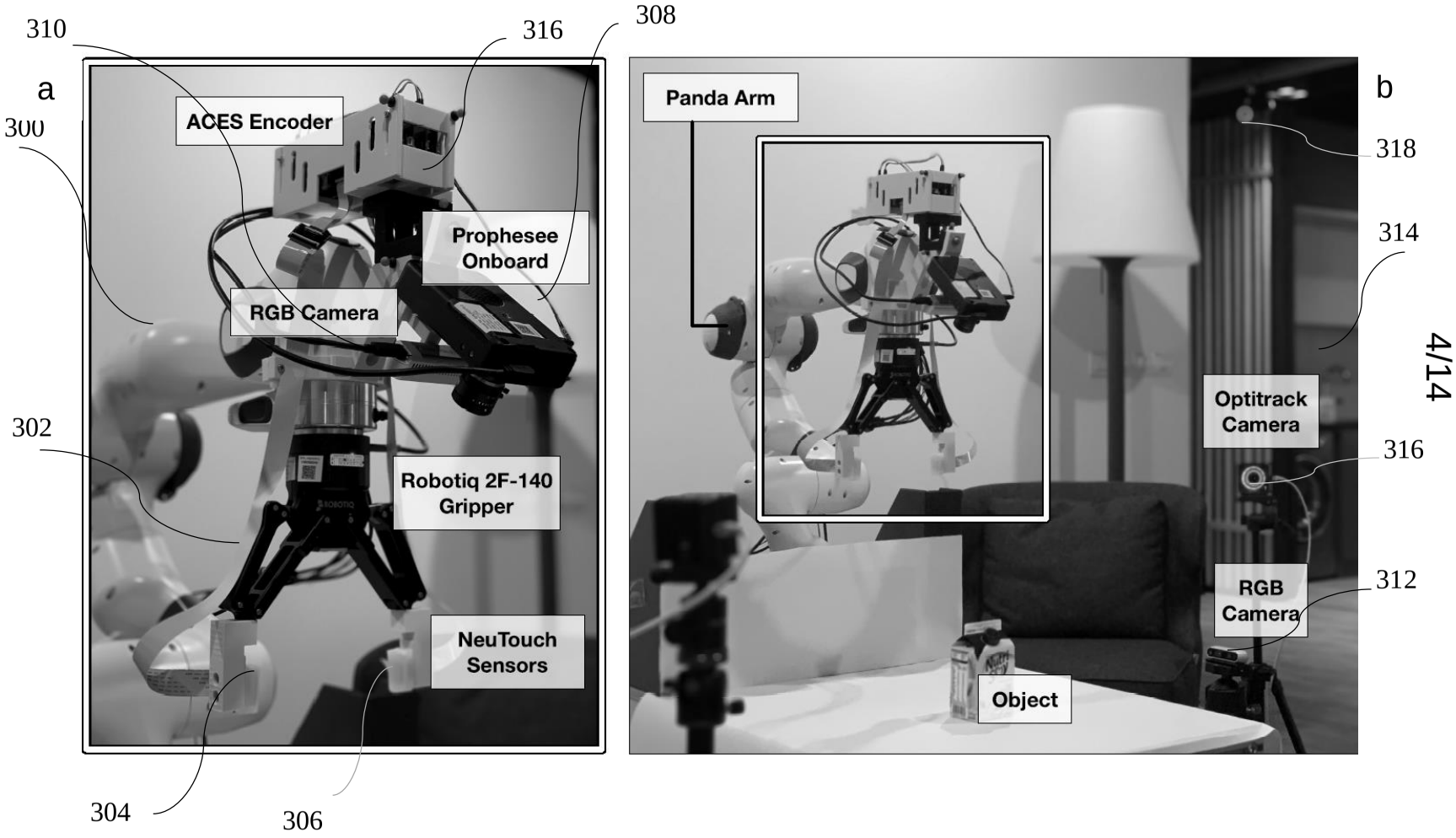

a
310
316
308
300
ACES Encoder
Prophesee Onboard
RGB Camera
302
Robotiq 2F-140 Gripper
NeuTouch Sensors
304
306
b
Panda Arm
318
314
Optitrack Camera
316
RGB Camera
312
Object

Figure 3

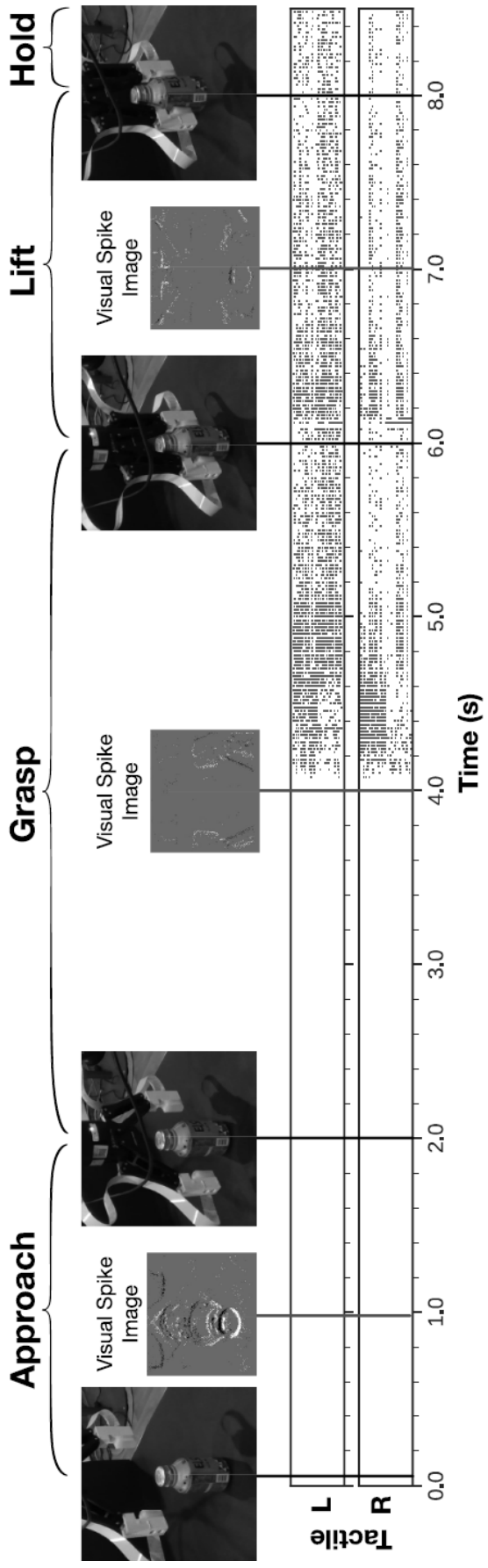

Approach
Grasp
Lift
Hold
Visual Spike Image
Visual Spike Image
Visual Spike Image
Tactile
L
R
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Time (s)

Figure 4



Figure 5

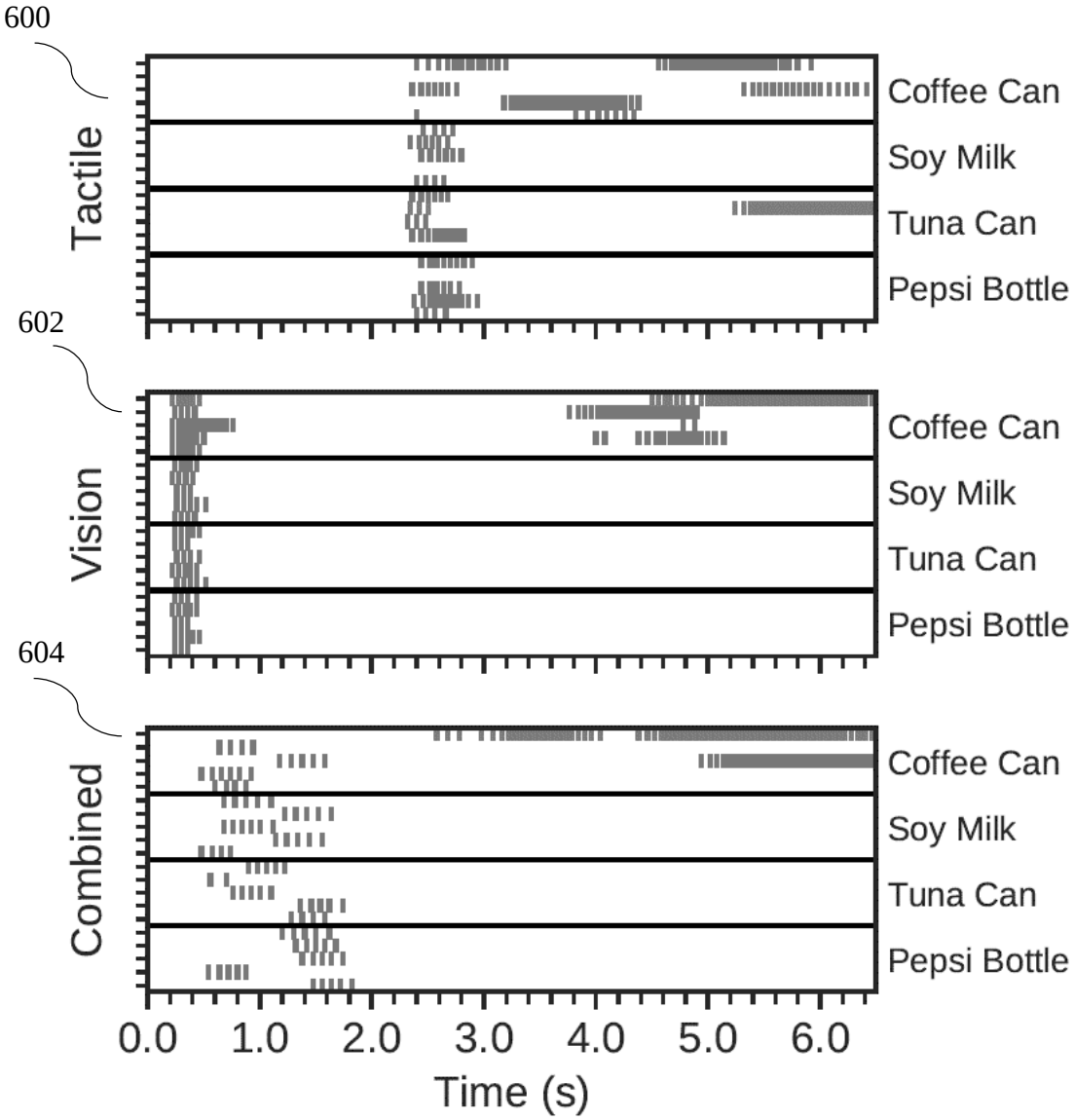


Figure 6

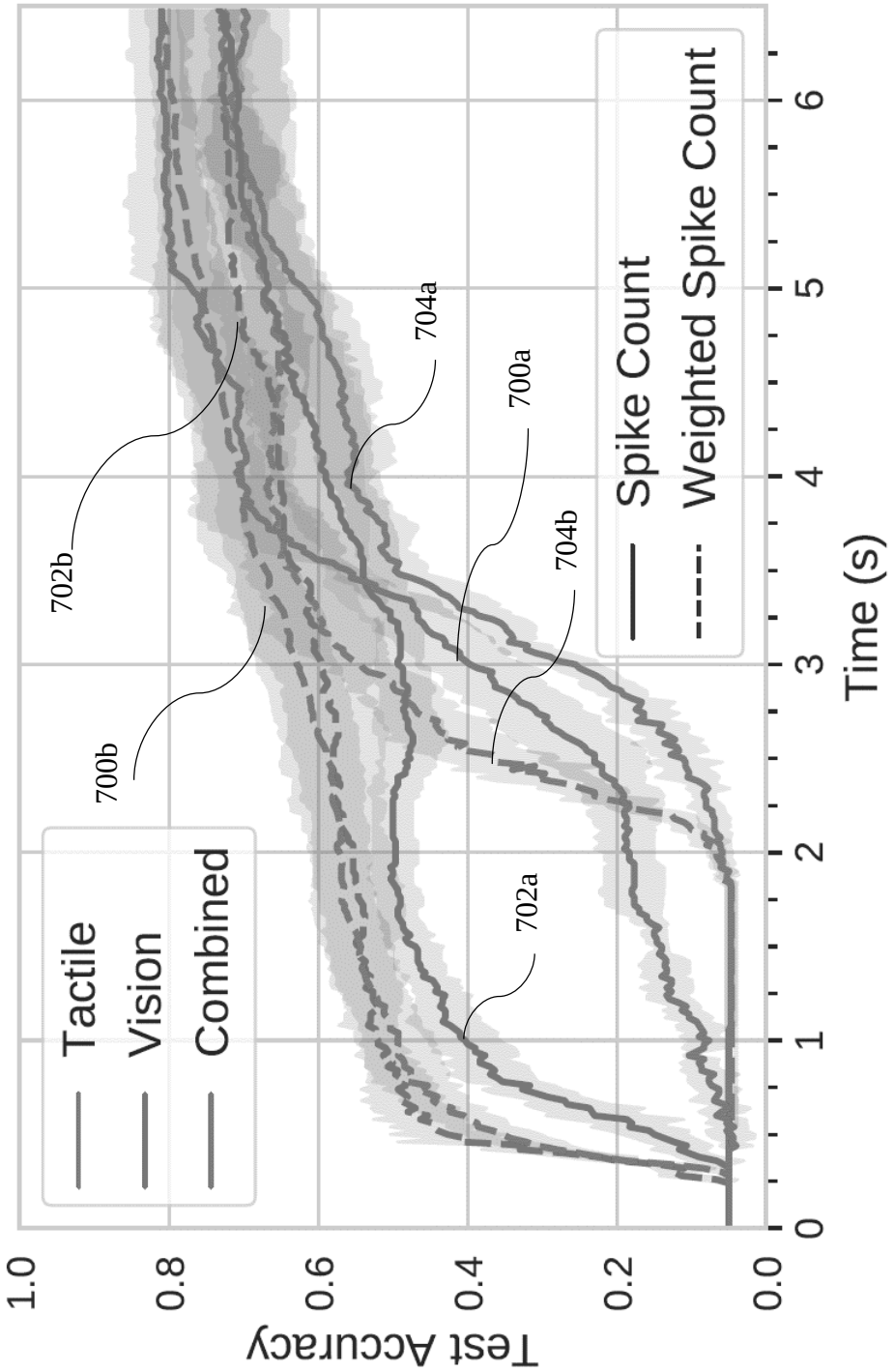

Tactile
Vision
Combined
Spike Count
Weighted Spike Count
Test Accuracy
Time (s)
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
700a
700b
702a
702b
704a
704b

Figure 7

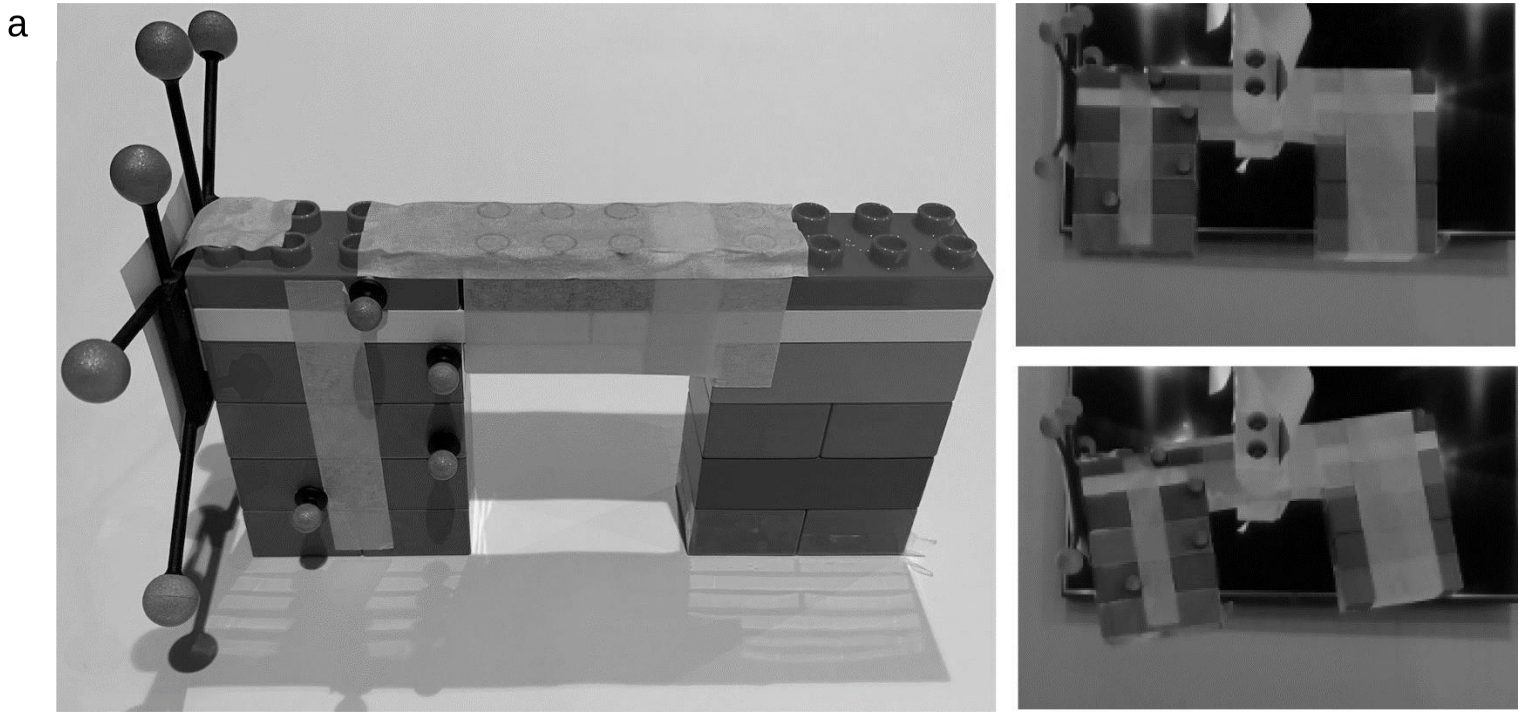


Figure 8

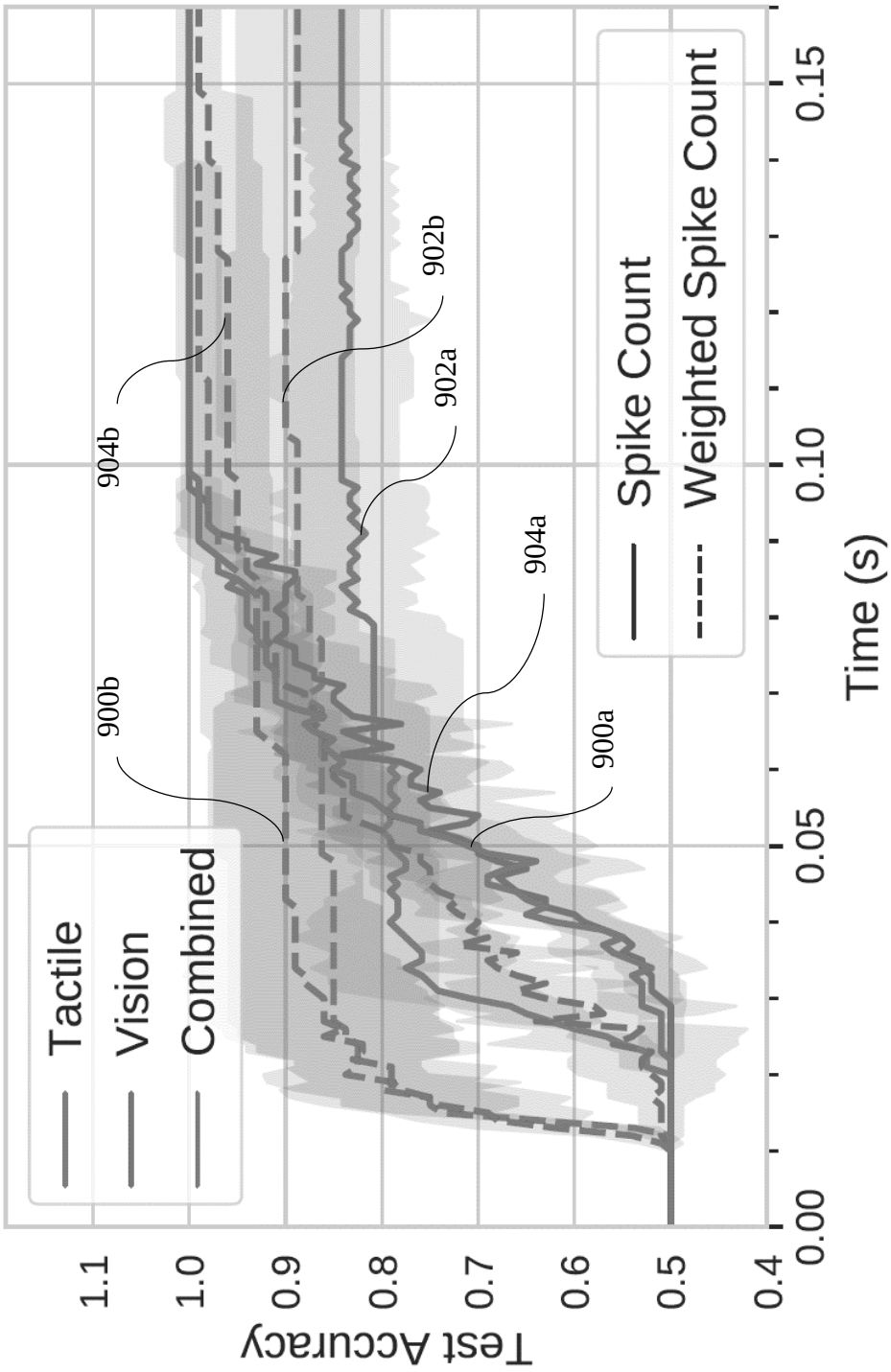

Tactile
Vision
Combined
Spike Count
Weighted Spike Count
900b
900a
902b
902a
904b
904a
Test Accuracy
Time (s)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.00
0.05
0.10
0.15

Figure 9

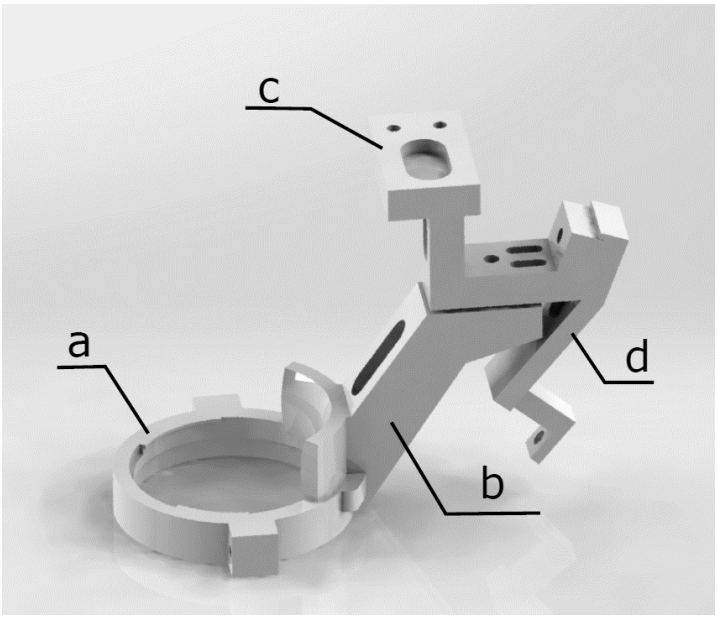


Figure 10

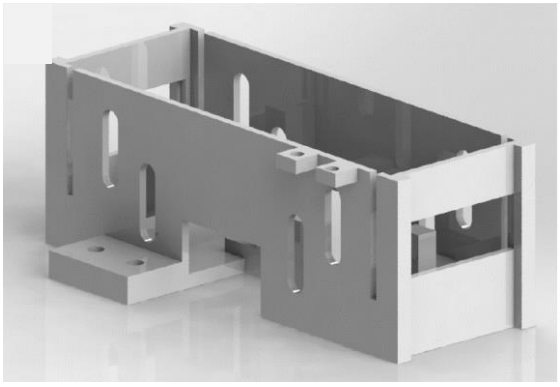


Figure 11

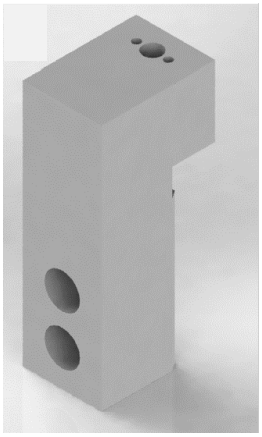


Figure 12

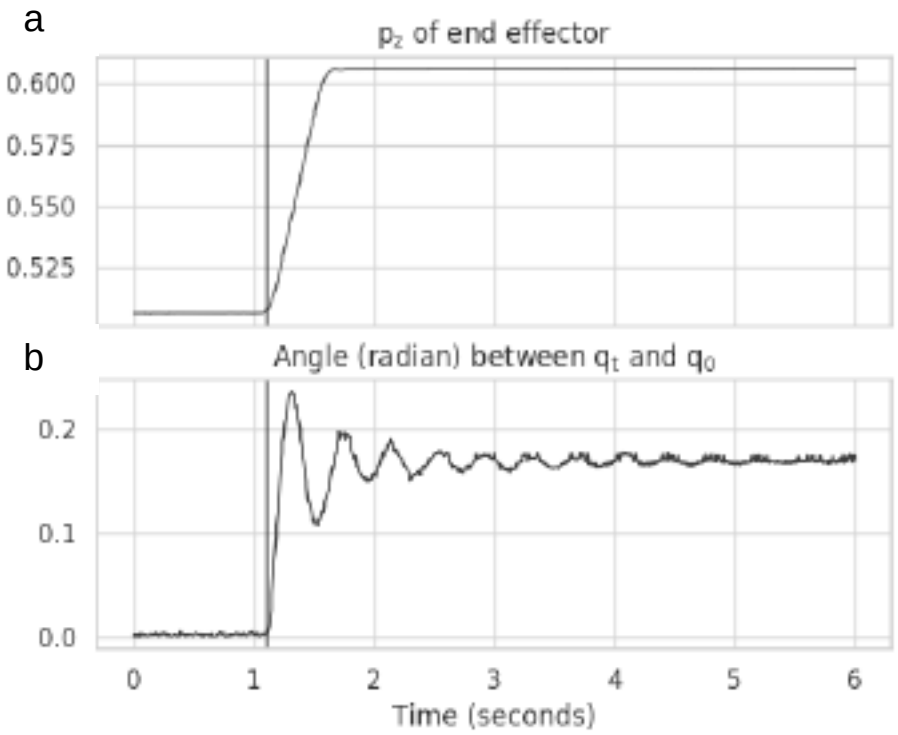


Figure 13

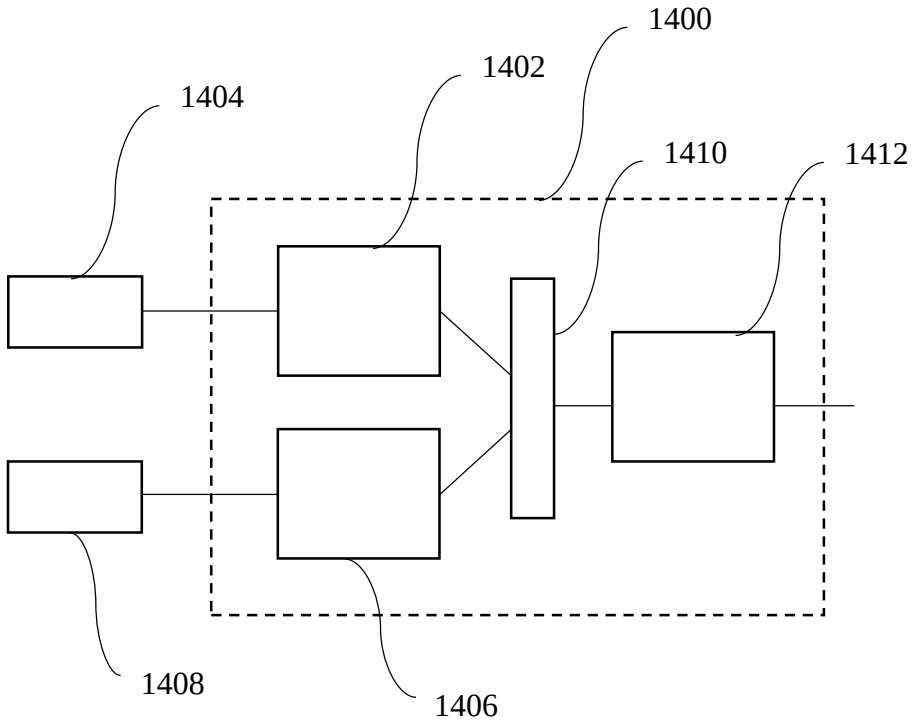


Figure 14

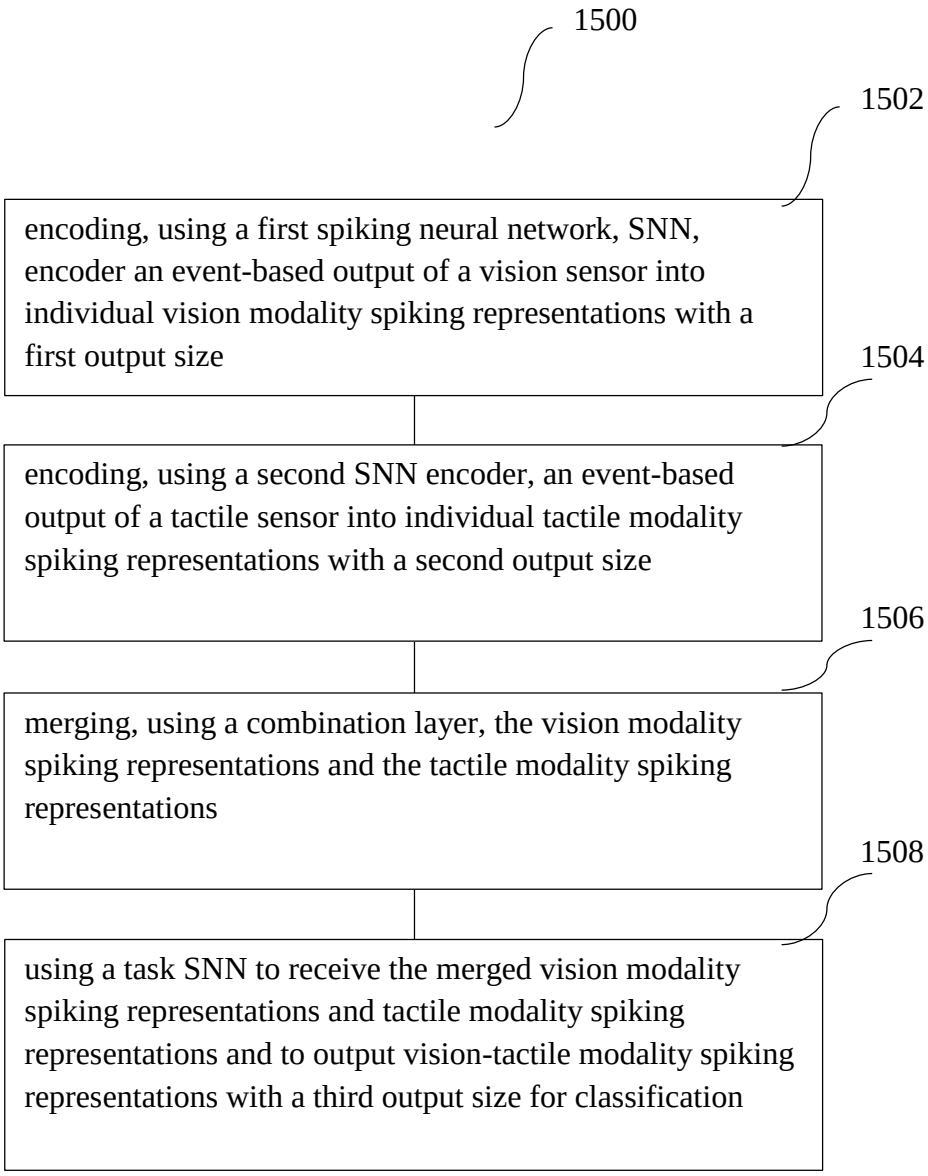

1500
1502
encoding, using a first spiking neural network, SNN, encoder an event-based output of a vision sensor into individual vision modality spiking representations with a first output size
1504
encoding, using a second SNN encoder, an event-based output of a tactile sensor into individual tactile modality spiking representations with a second output size
1506
merging, using a combination layer, the vision modality spiking representations and the tactile modality spiking representations
1508
using a task SNN to receive the merged vision modality spiking representations and tactile modality spiking representations and to output vision-tactile modality spiking representations with a third output size for classification

Figure 15

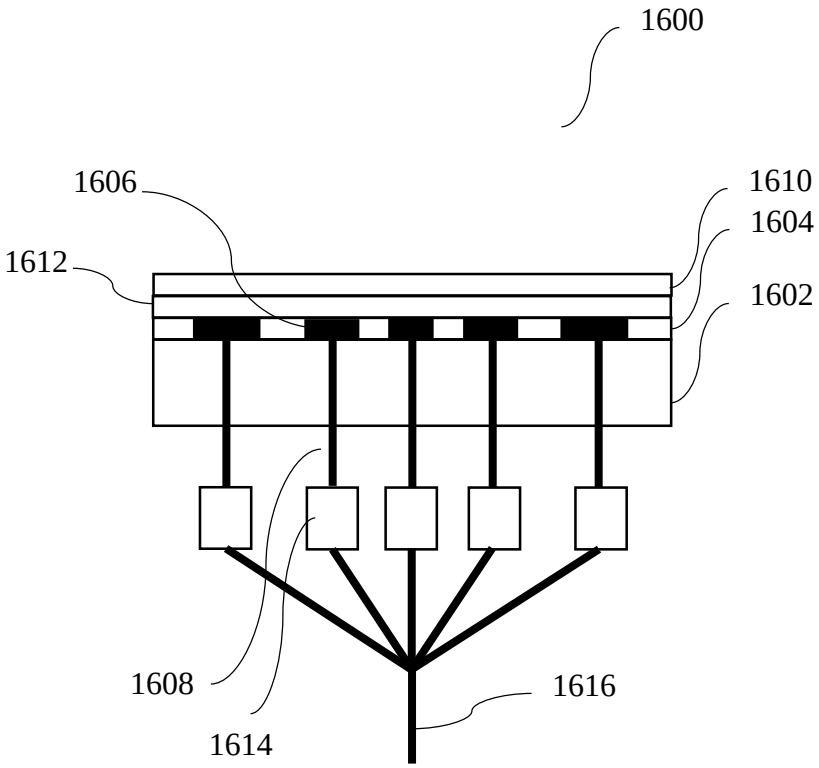


Figure 16

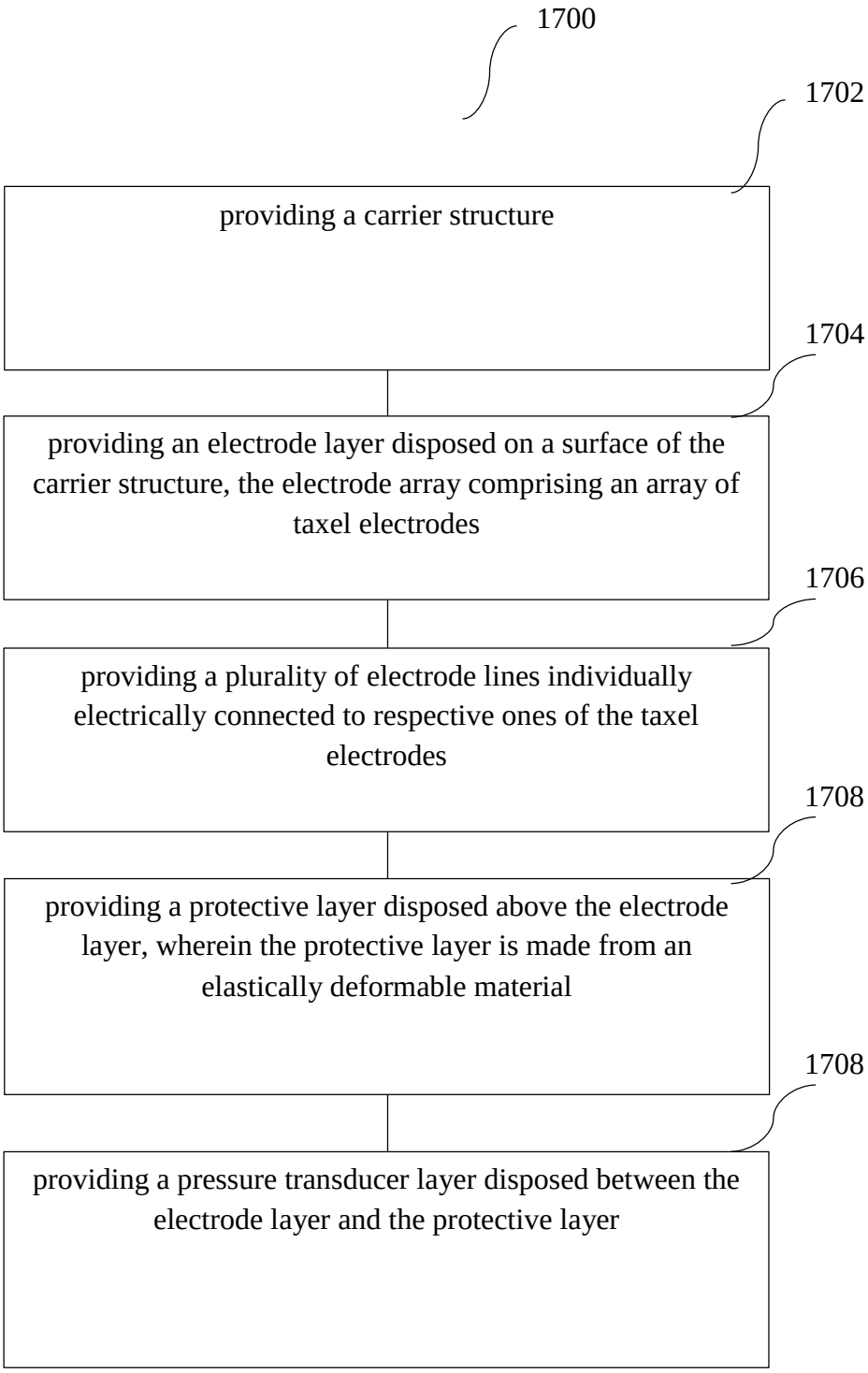

1700
1702
providing a carrier structure
1704
providing an electrode layer disposed on a surface of the carrier structure, the electrode array comprising an array of taxel electrodes
1706
providing a plurality of electrode lines individually electrically connected to respective ones of the taxel electrodes
1708
providing a protective layer disposed above the electrode layer, wherein the protective layer is made from an elastically deformable material
1708
providing a pressure transducer layer disposed between the electrode layer and the protective layer

Figure 17