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Dorsal-Ventral place cell representations in multi-scale environments

B. Harland[1], M. Contreras[1], P. Scleidorovich[2], Weitzenfeld[2], J.-M. Fellous[1,3]

1. Dept. of Psychology, Univ. of Arizona, Tucson, AZ; 2. Dept. of Computer Sci. and Engin., Univ. of South Florida, Tampa, FL; 3. Dept. of Biomedical Engin., Univ. of Arizona, Tucson, AZ

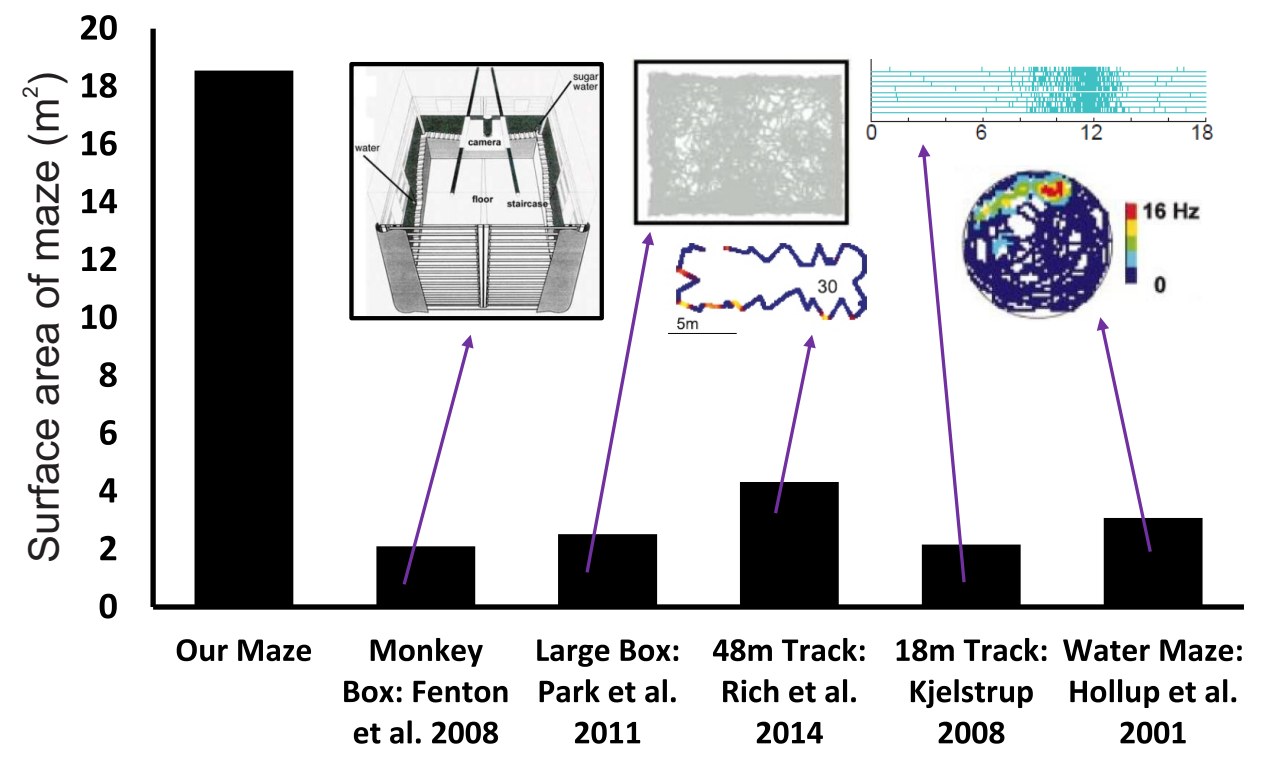
Introduction

Place cells (O'Keefe and Dostrovsky, 1971) are hippocampal neurons that generally exhibit one 'place field' in small environments. There is evidence that place cells can show multiple place fields in larger environments (Rich et al., 2014; Park et al., 2011) but it remains unclear how place cells along the dorsal-ventral hippocampal axis may contribute to a multi-scale representation in a much larger open space (Harland et al., 2017). There is recent evidence that ventral place cells may become more relevant in larger or more complex environments (Contreras et al., 2018).

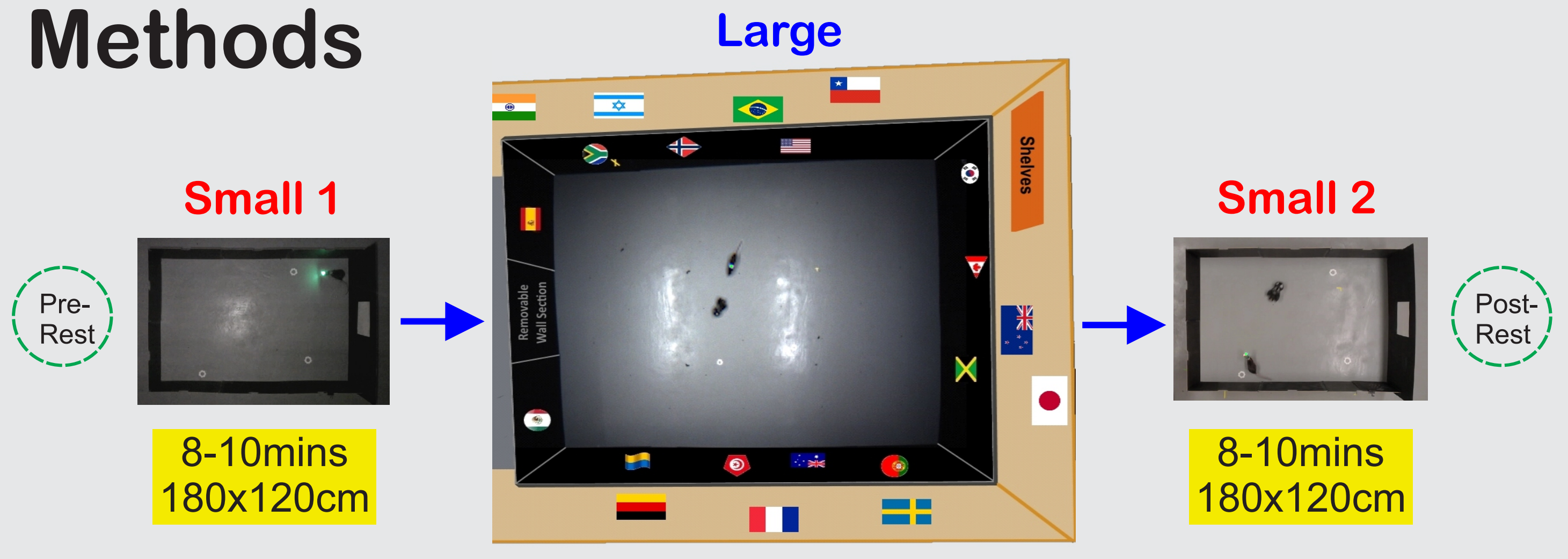
Place fields have been shown to be plastic, to depend on reward locations and on the presence of obstacles and maze-cues (Aikath et al., 2014; Rivard et al., 2004; Hollup et al., 2001). Their plasticity across environments of very different sizes is however unclear.

We recorded hippocampal place cells in a large open space using wireless recording and a new navigational paradigm in which the rat chased a small robot.

The area of the large environment used in the current study is over four times larger than most previously used environments



Methods

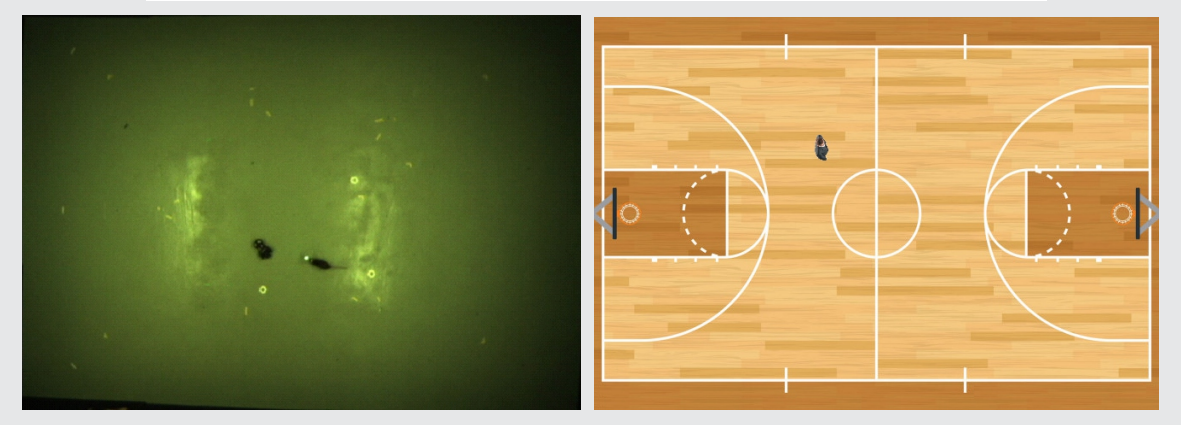


8-10mins
180x120cm

40-50mins
530x350cm

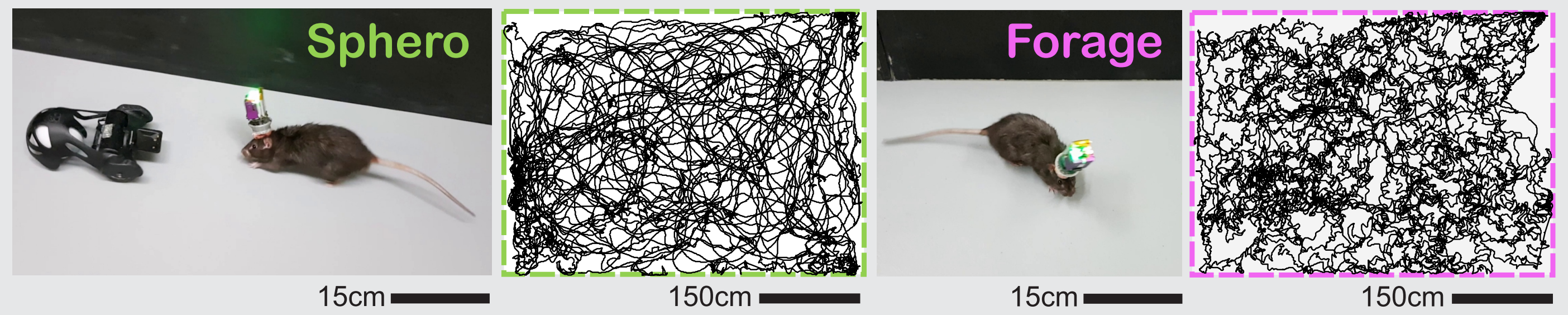
8-10mins
180x120cm

The large environment for the rat is equivalent in size to a basketball court with sidelines for a human



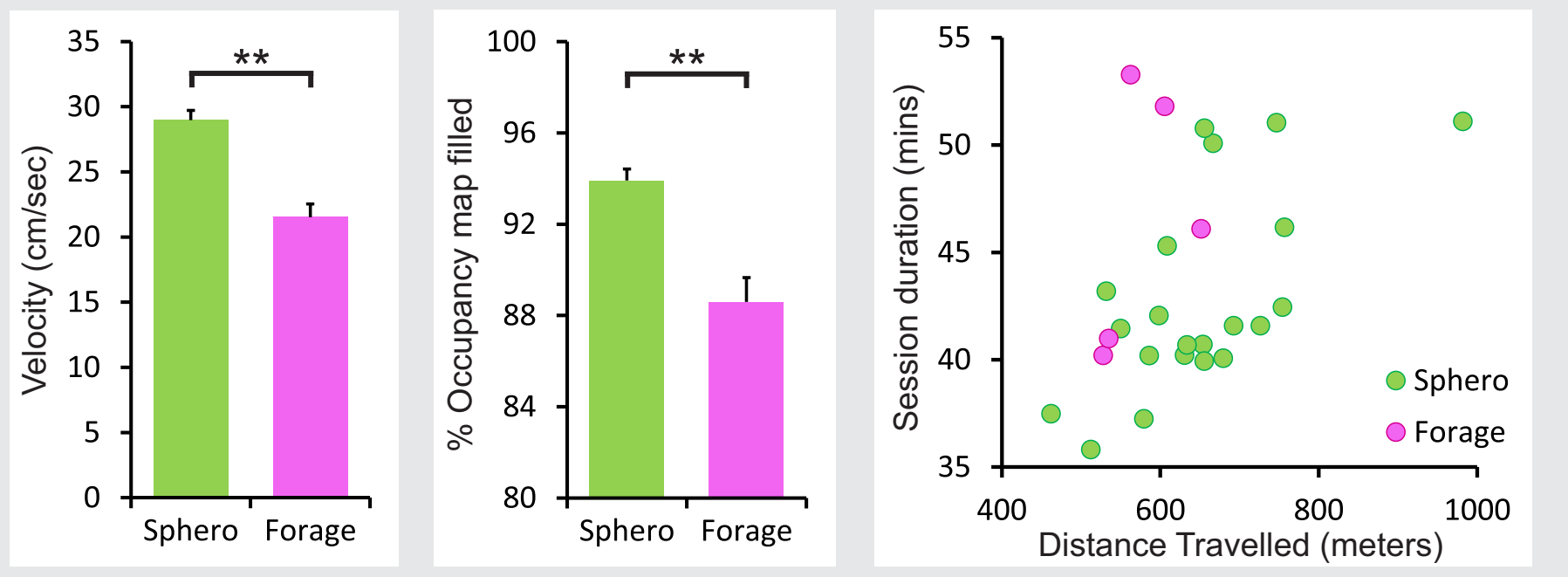
Hippocampal neurons and local field potentials were wirelessly recorded while five rats navigated in different sized environments containing intra- & extra- maze cues.

In most sessions, the rat chased a small 'Sphero' robot baited with food (Gianelli et al., 2017). In other sessions the rat foraged for food pellets scattered on the floor.

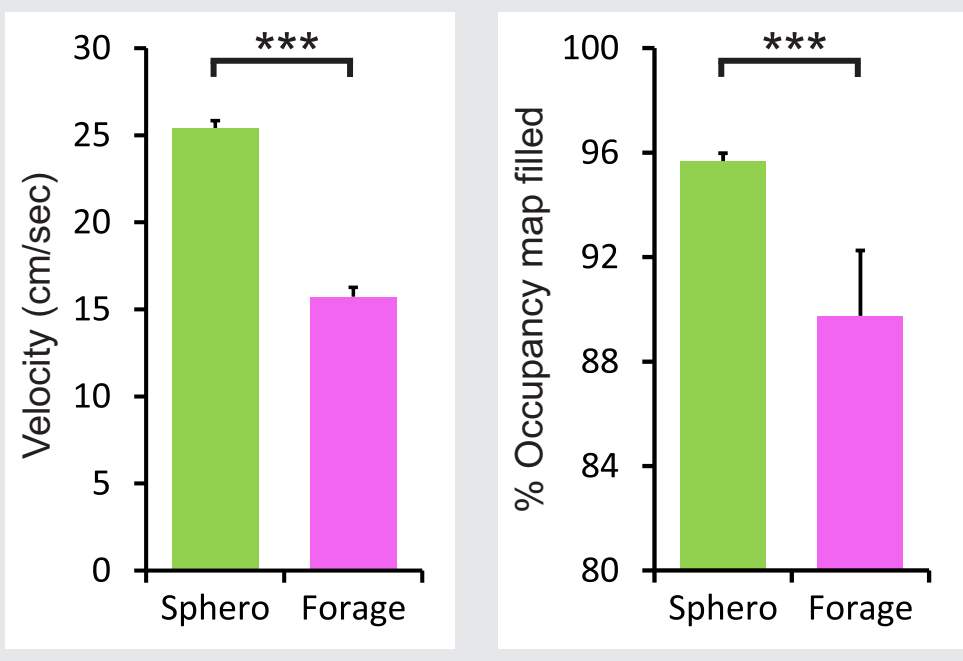


Rats moved faster and covered more space in Sphero sessions (n=21) compared to Foraging sessions (n=5) in both small and large environments

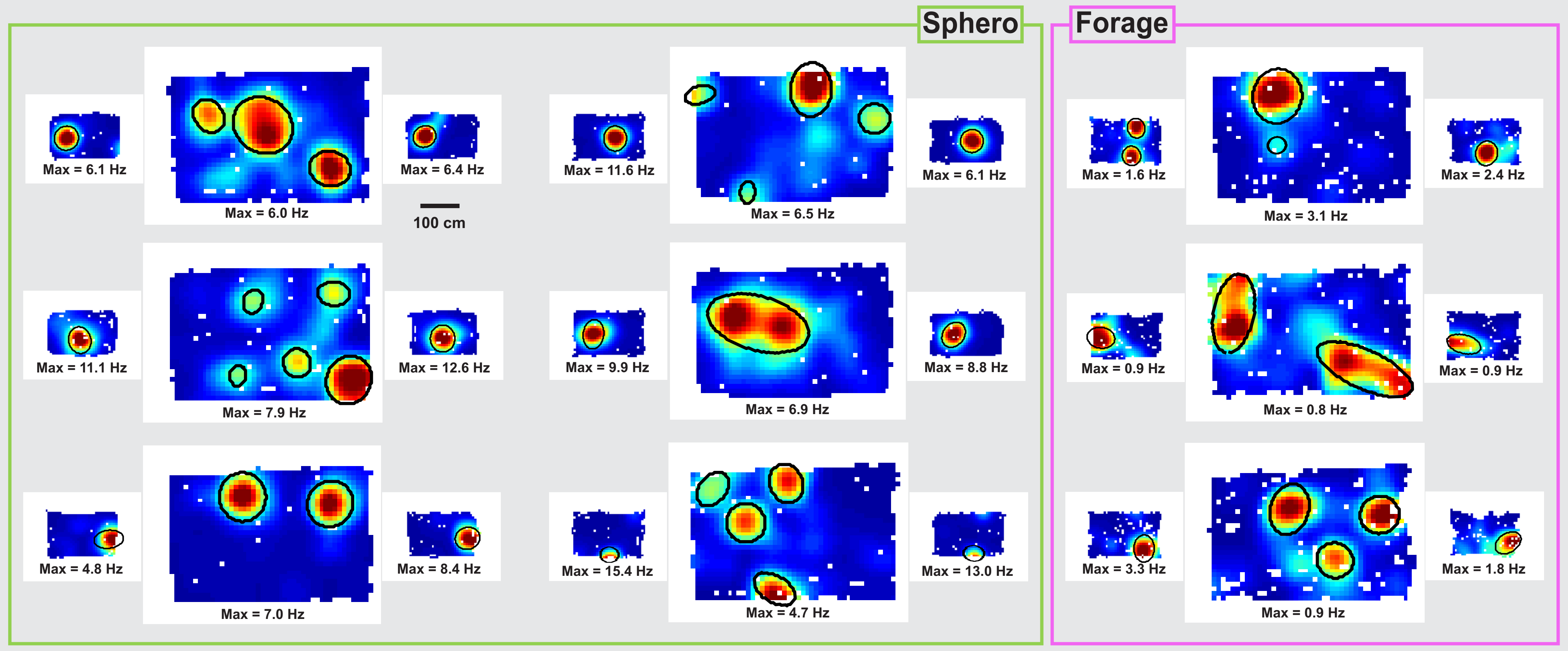
Large Environment



Small Environments



Dorsal CA1 Place Fields



Place Fields Properties

All recorded cells fired in the large environment
307 dorsal cells were isolated from 26 sessions, 75% of these cells fired in both small environments, whereas 100% of the cells fired in the large environment.

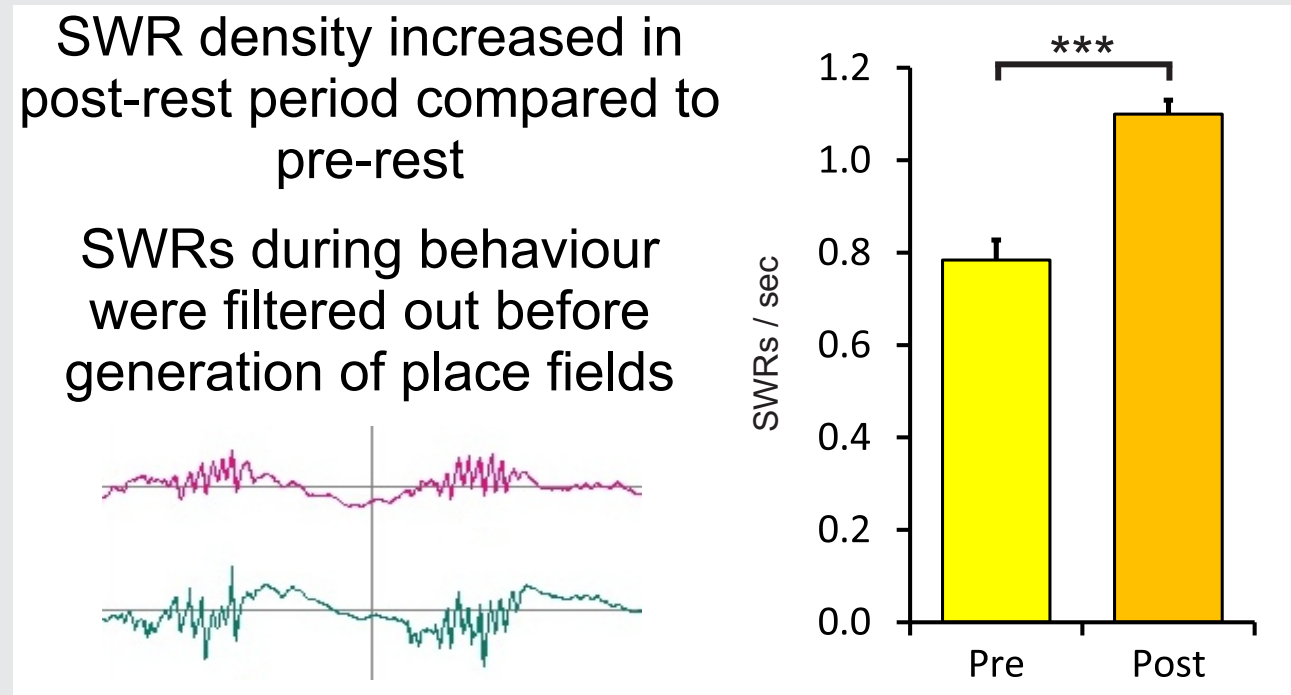
225 cells (174 Sphero, and 51 Forage) had ratemap correlations between the small environments that were 2 standard deviations above the shuffled mean for that cell (300 shuffles).

The distributions of number of fields, average and total field size, mean firing rate, number of spikes, and mean place field intensity **were not different for Forage vs Sphero sessions** (p's > 0.09)**, so cells were pooled.**

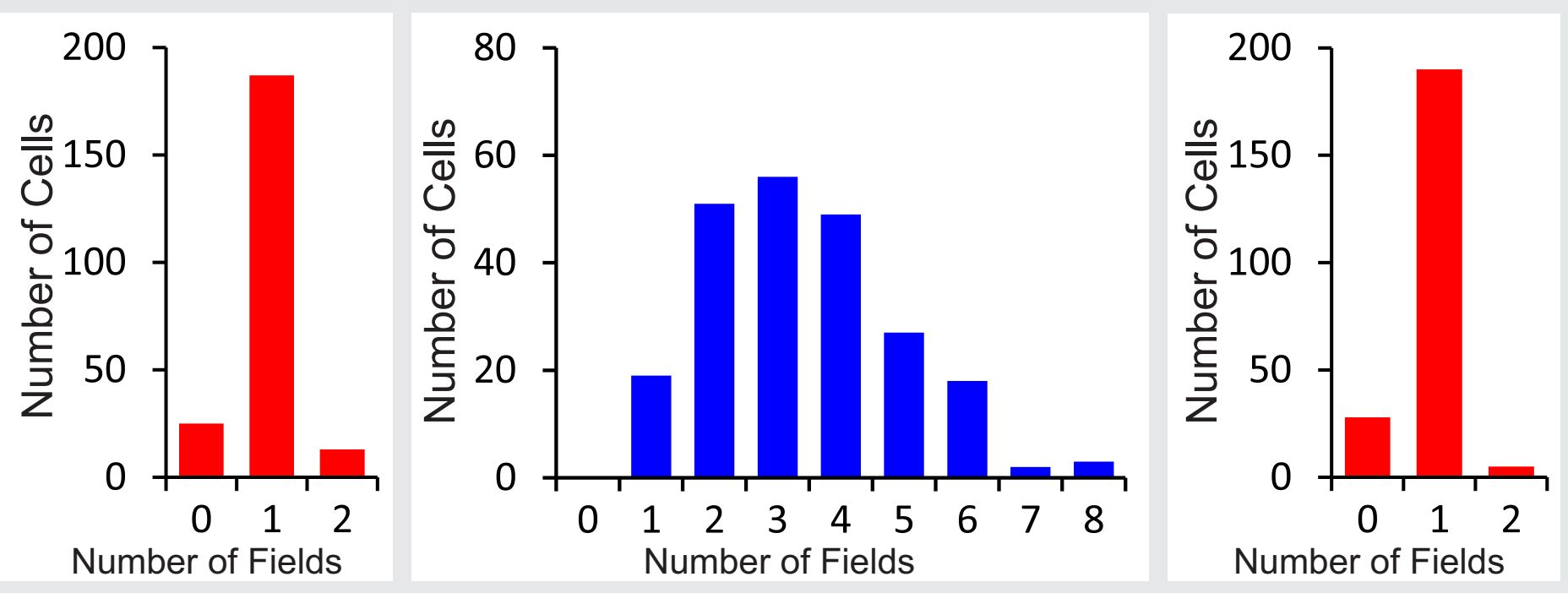
Sharp Wave Ripples (SWRs)

SWR density increased in post-rest period compared to pre-rest

SWRs during behaviour were filtered out before generation of place fields

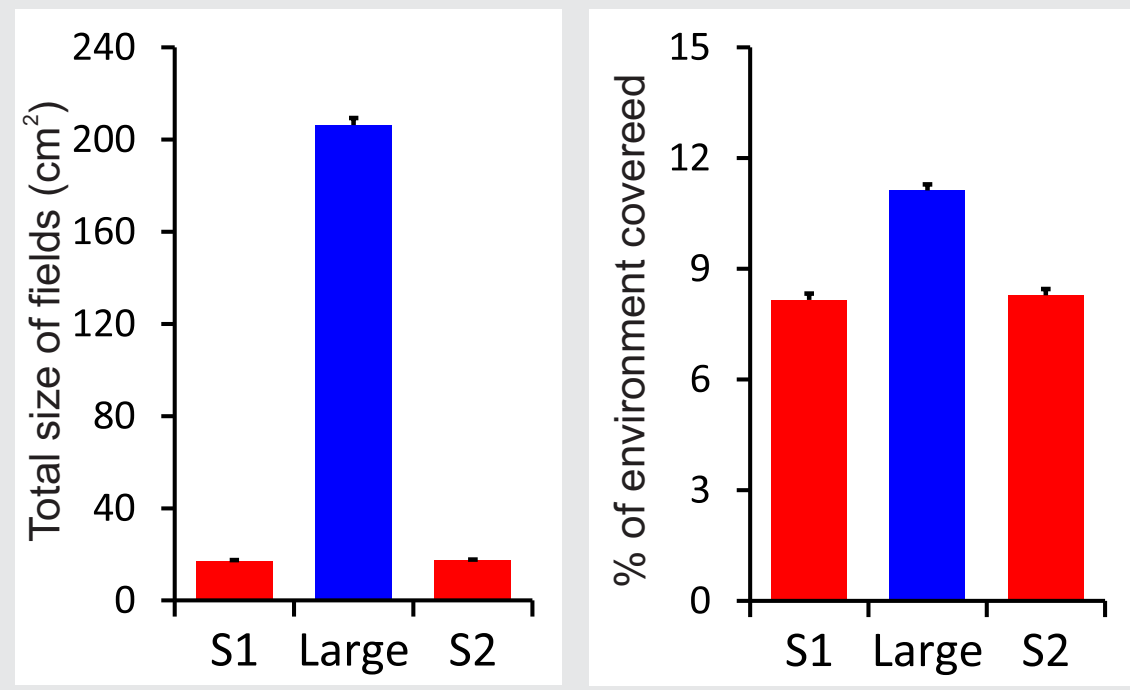


Number of place fields per cell

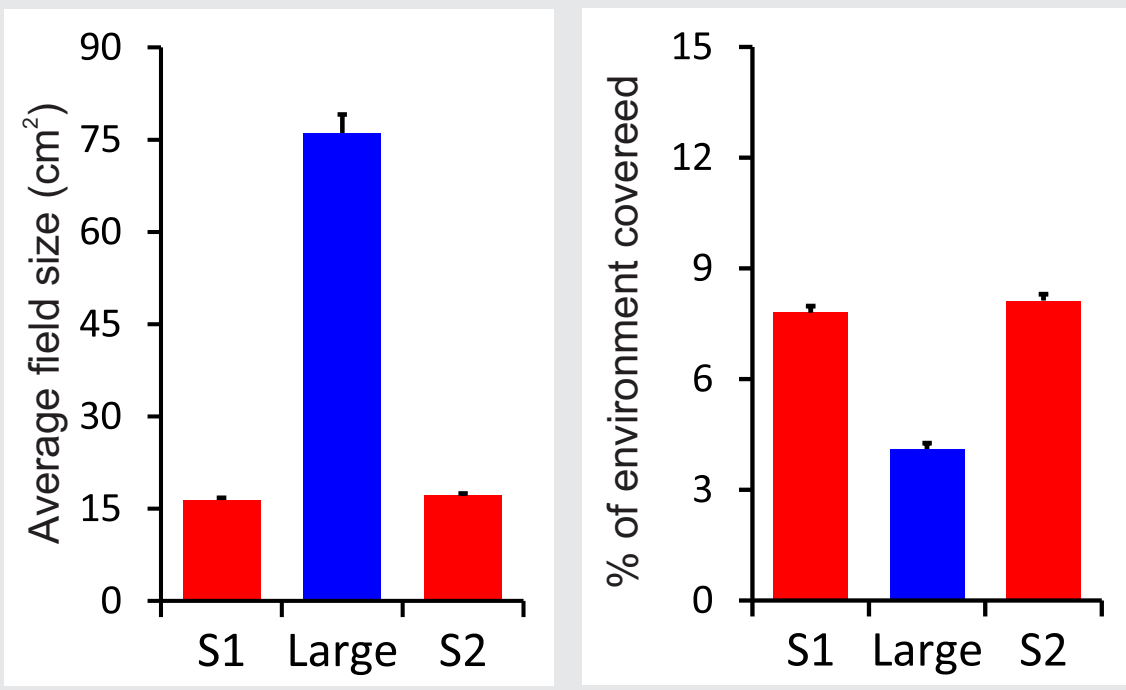


Small 1 Large Small 2

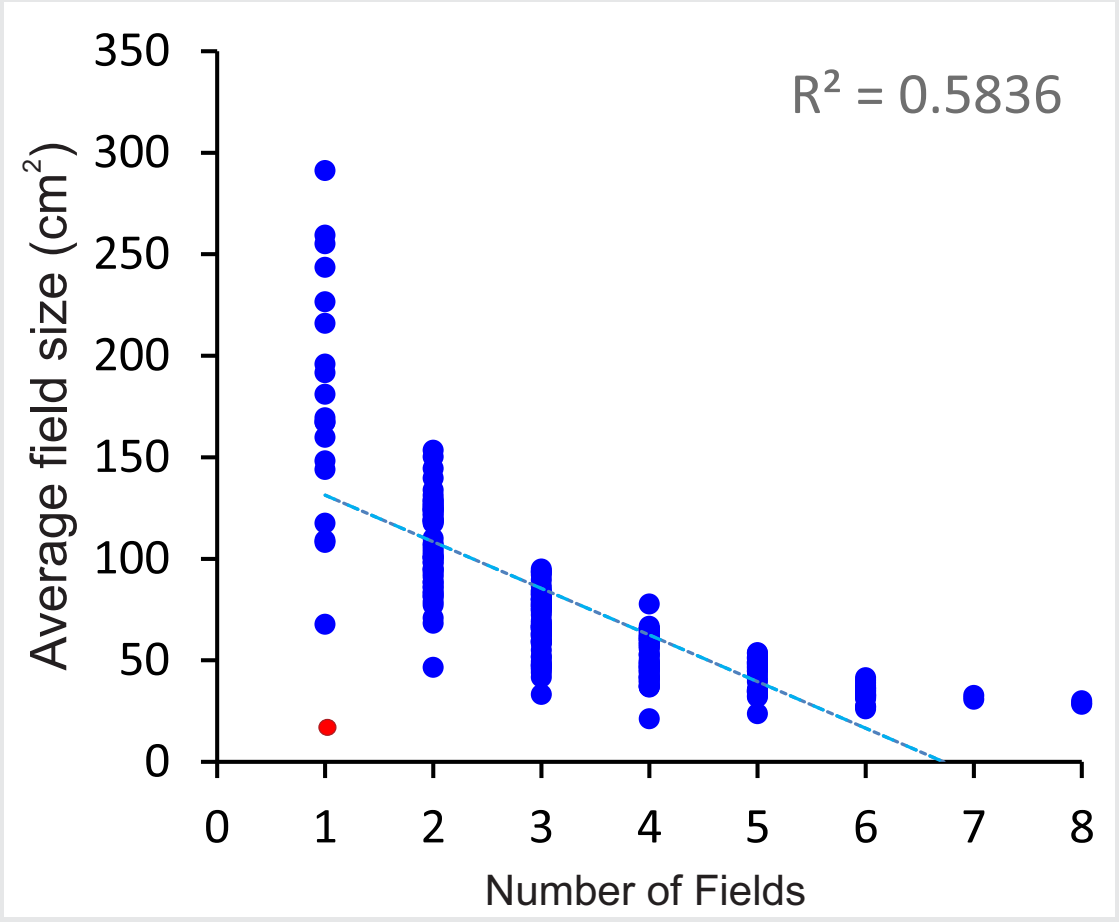
Total area of all fields



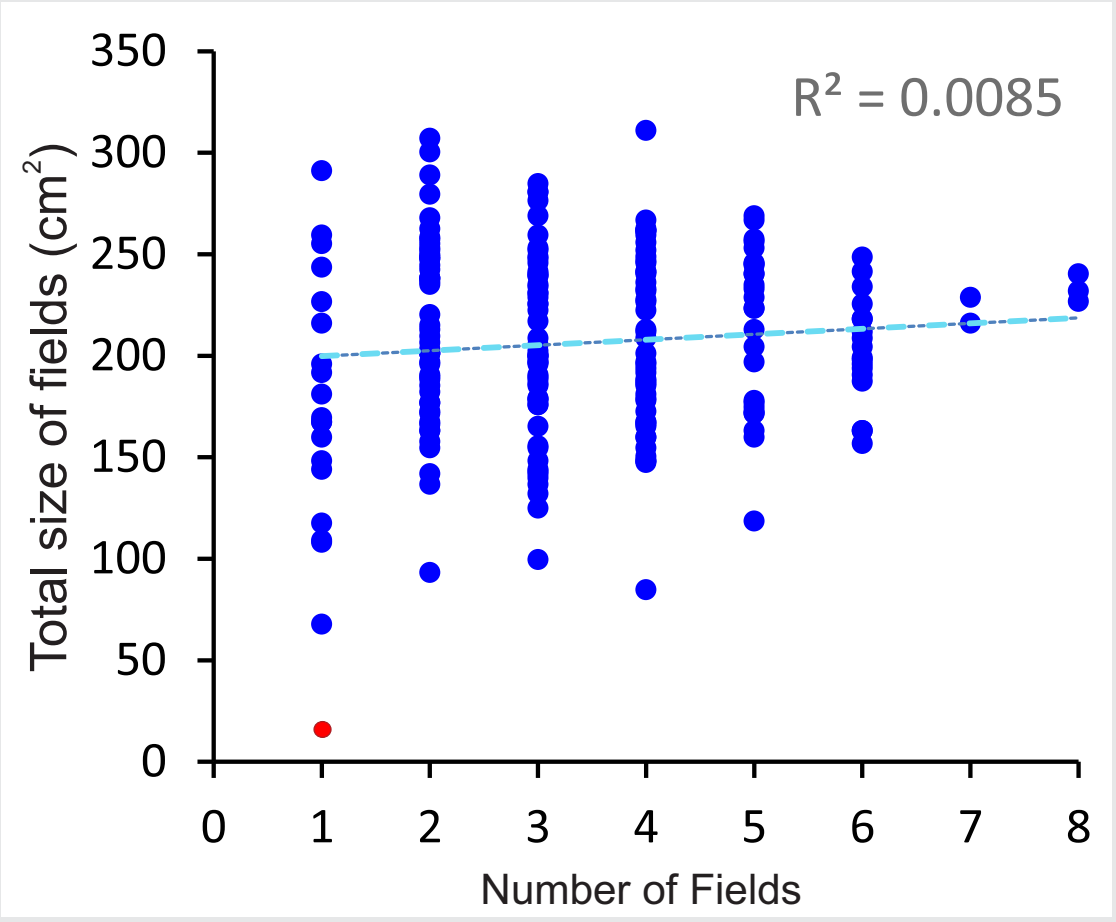
Average field size



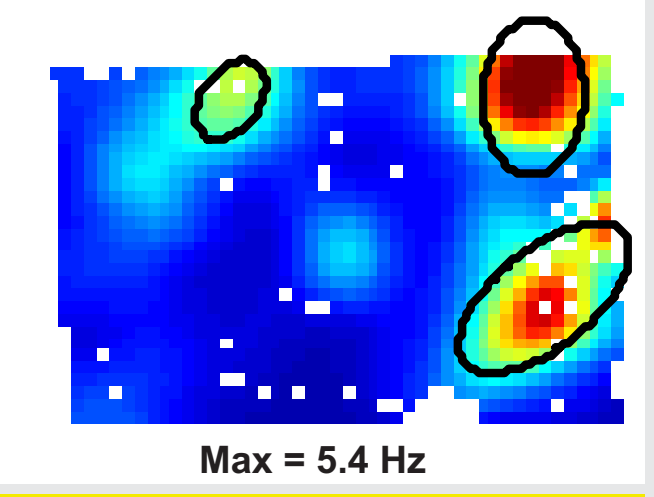
Place cells in a large environment may be better characterized as 'area cells'.



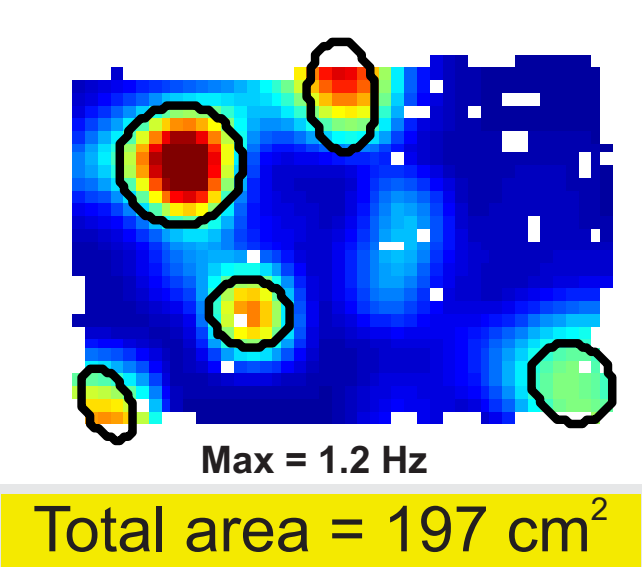
More place fields in 'Large' = smaller average field size



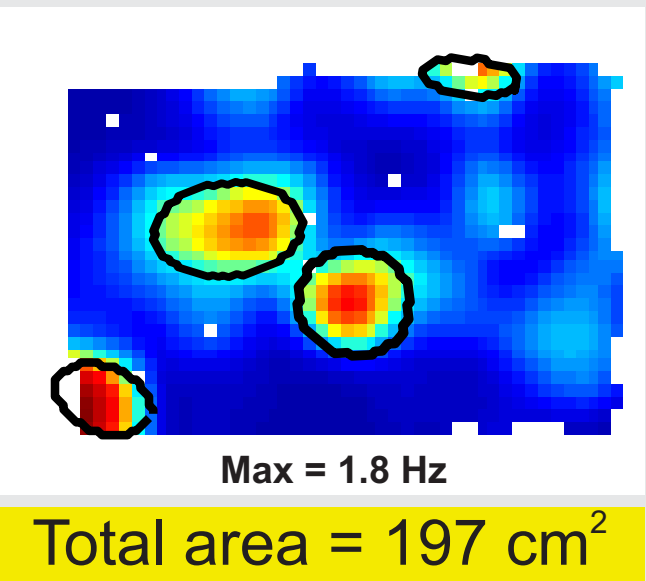
However, the total size per cell of all fields is conserved



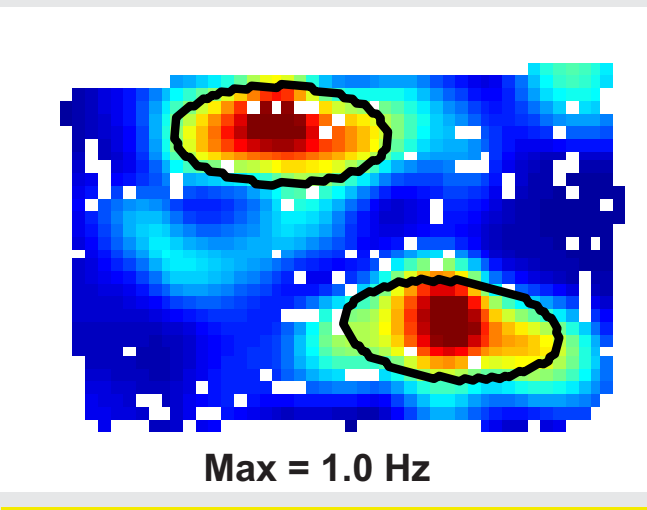
Total area = 200 cm²



Total area = 197 cm²



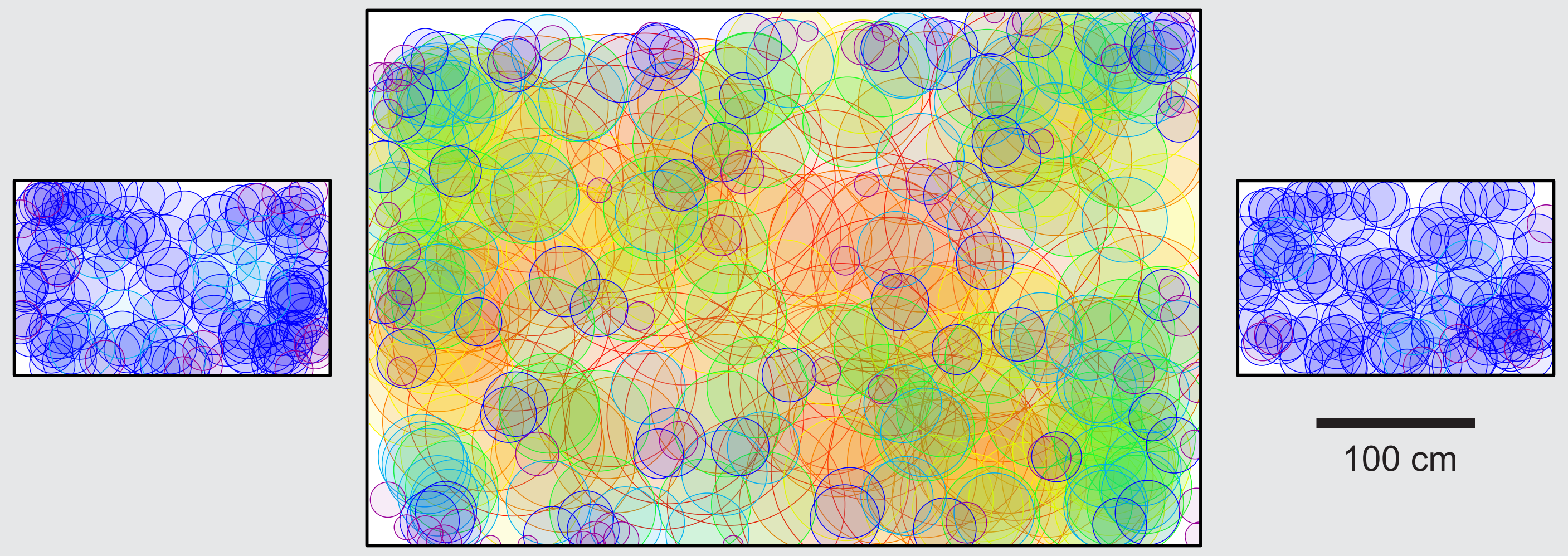
Total area = 197 cm²

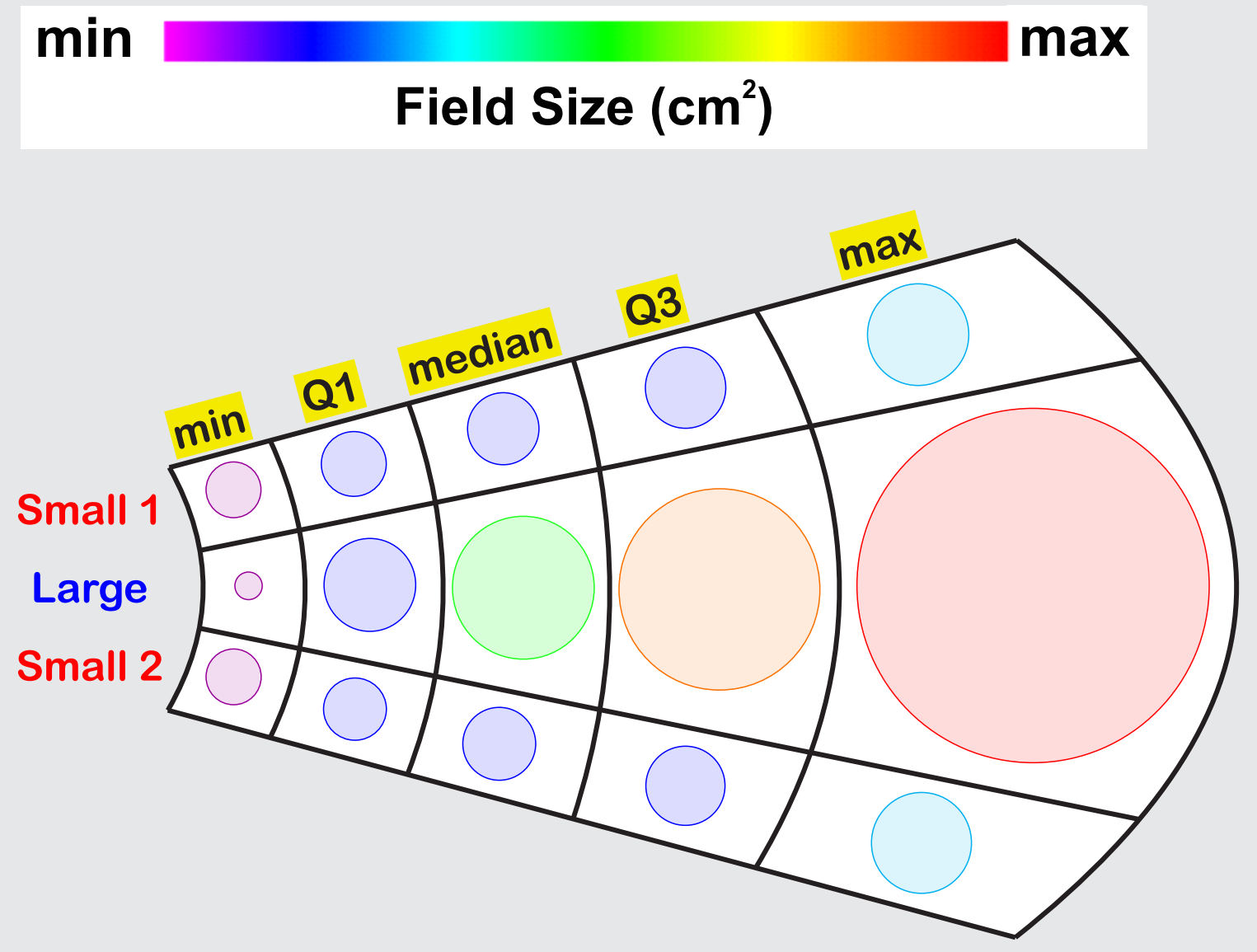


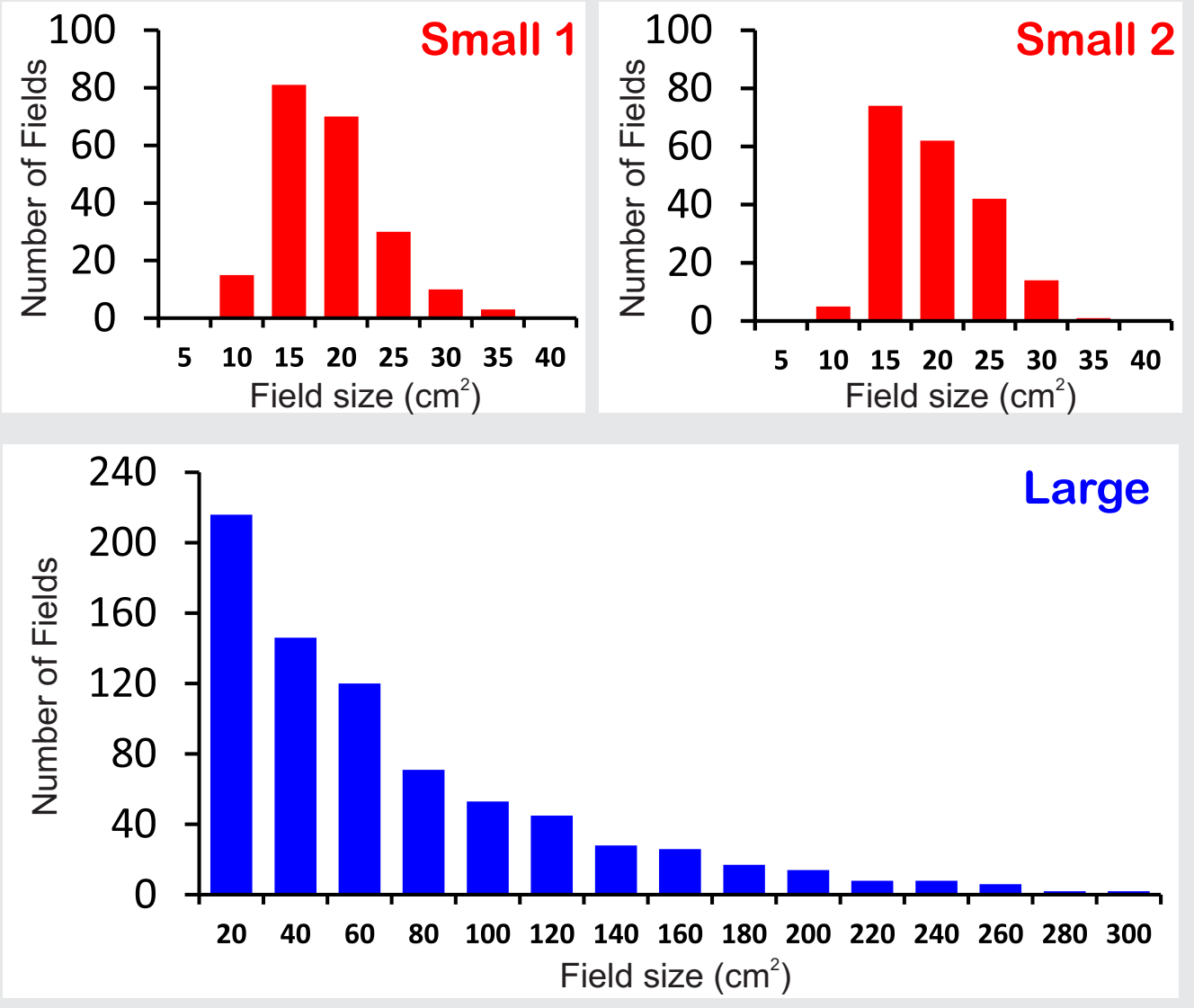
Total area = 203 cm²

Population Data

Dorsal place fields form a 'multi-scale' representation in the large environment
'Idealized' place fields from a sub-population of 145 cells are shown below

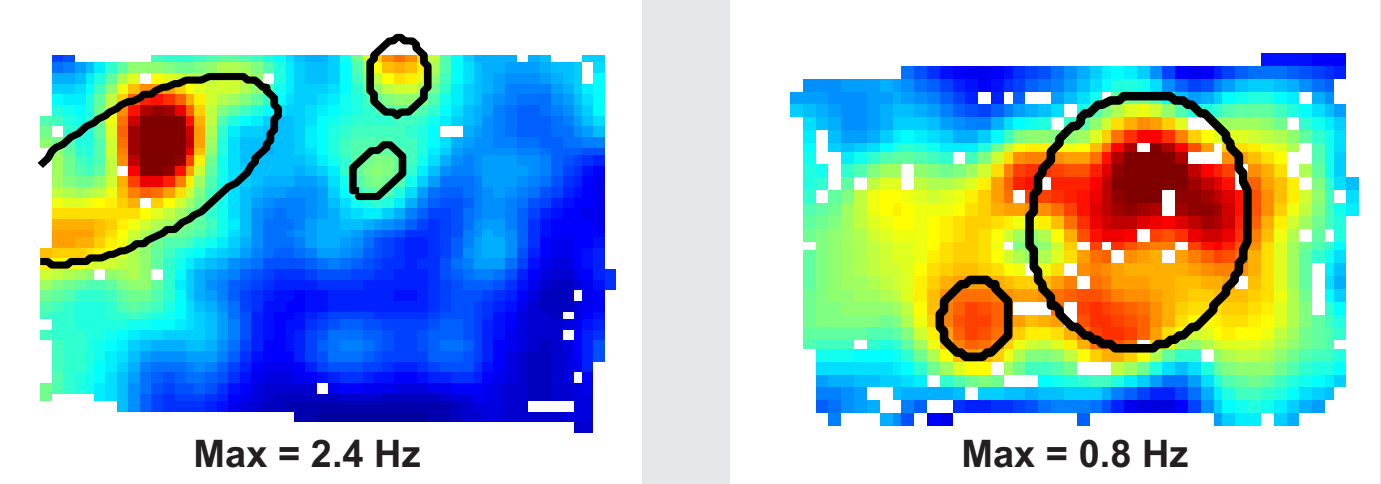


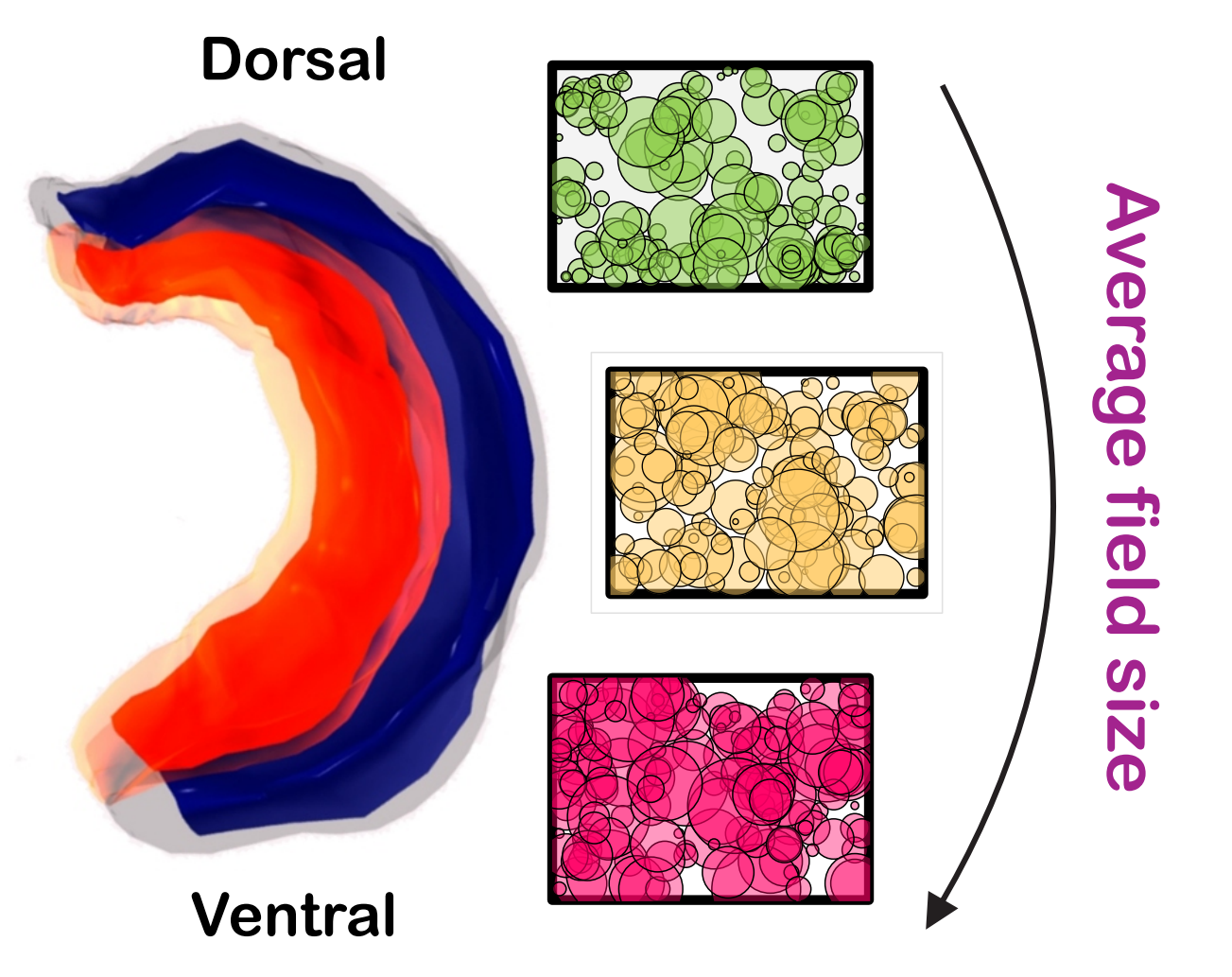




Ventral CA1

Ventral place cells also exhibit larger multiple fields of varying size, however, more data is needed.





Conclusions

- **The 'Sphero' robot is a useful tool for achieving the spatial coverage required for recording electrophysiological data in a large environment**
- **Dorsal place cells exhibit varying numbers and sizes of spatial fields in the large environment, aggregating to a similar total area across cells**
- **The population of dorsal place fields may form a multi-scale representation of large environments**
- **Ventral place fields may also contribute to a multi-scale representation and may be a coarser-scaled version of the dorsal representation**

References

Aikath D, Weible AP, Rowland DC, Kentros CG (2014) Role of self-generated odor cues in contextual representation. *Hippocampus*, 24(8): 1039-51; Contreras M, Pelc T, Llofriu M, Weitzenfeld A, Fellous JM (2018) The ventral hippocampus is involved in multi-goal obstacle-rich spatial navigation. *Hippocampus*, doi: 10.1002/hipo.22993; Fenton AA, Kao HY, Neymotin SA, et al. (2008) Unmasking the CA1 ensemble place code by exposures to small and large environments: more place cells and multiple, irregularly arranged, and expanded place fields in the larger space. *J Neurosci*, 28(44): 11250-62; Gianelli S, Harland B, Fellous J-M (2017) A rat-compatible robotic framework for behavioural neuroscience experiments. *Journal of Neuroscience Methods*, 294: 40-50; Harland B, Contreras M, Fellous J-M (2017) A role for the longitudinal axis of the hippocampus in multiscale representations of large and complex spatial environments and mnemonic hierarchies. In: Stuchlik A, editor. *The Hippocampus – Plasticity and Functions*. Rijeka: InTechOpen; DOI: 10.5772/intechopen.71165; Hollup SA, Molden S, Donnett JG, Moser M-B, Moser E (2001) Accumulation of hippocampal place fields at the goal location in an annular watermaze task. *Journal of Neuroscience*, 21(5): 1635-1644; Kjelstrup KB, Solstad T, Brun VH, Hafting T, Leutgeb S, Witter MP, Moser EI, Moser MB (2008) Finite scale of spatial representation in the hippocampus. *Science*, 321(5885): 140-3; O'Keefe J, Dostrovsky J (1971) The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain Res*, 1: 171-5; Park E, Dvorak D, Fenton AA (2011) Ensemble place codes in hippocampus: CA1, CA3, and dentate gyrus place cells have multiple place fields in large environments. *PLoS One*, 6(7): e22349; Rich PD, Liaw HP, Lee AK (2014) Place cells. Large environments reveal the statistical structure governing hippocampal representations. *Science*, 345(6198): 814-7; Rivard B, Li Y, Lenck-Santini PP, Poucet B, Muller RU (2004) Representation of objects in space by two classes of hippocampal pyramidal cells. *J Gen Physiol*, 124(1): 9-25.

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Contact Information: qteeftw@gmail.com