LETTER

REPLY TO MUSCOLONI AND CANNISTRACI: Navigation performance measures

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Muscoloni and Cannistraci (1) comment on our motivation and rationale for using the efficiency ratio to assess the feasibility of navigation routing as a model of communication in nervous systems embedded in Euclidean space (2). Recent work by these authors in the field of network physics evaluates navigation in hyperbolic space using the greedy routing score (3), a measure equivalent to the efficiency ratio.

The efficiency ratio (E_R) is the ratio of the efficiency of navigation paths (E) to that of shortest paths (E^*). We used the efficiency ratio to demonstrate that the topology and geometry of mammalian cortical networks allows for near-optimal decentralized communication under navigation routing. We provided a mathematical definition of the efficiency ratio in equation 1 of ref. 2. Furthermore, we provided a rationale for using the efficiency ratio and described how this measure relates to the proportion of failed/successful navigation paths, previously quantified with the success ratio (4, 5). These details can be found in the main text of Seguin et al. (ref. 2, p. 2) in *Navigation Performance Measures* and in figure 2 of ref. 2. In particular, we wrote

> E quantifies both the number of failed paths and the efficiency of successful paths. We defined the efficiency ratio
>
> $$E_R = \frac{1}{N^2 - N} \sum_{i \neq j} \frac{\Lambda^*_{ij}}{\Lambda_{ij}} \quad [1]$$
>
> to compare navigation with shortest path routing. For any network, $E^* \geq E$ and thus $0 \leq E_R \leq 1$. The closer E_R is to 1, the better navigation is at finding paths that are as efficient as shortest paths.

Muscoloni and Cannistraci (1) also argue that "greedy routing" is a more appropriate terminology compared with "navigation" routing. Our choice of terminology was motivated by the common use of terms such as "navigability," "navigation problem," "navigation efficiency," and "navigation games," among others (4–6).

Our study shows that navigation routing is a feasible model of large-scale neural communication. We hope that our work will motivate further study of navigation and communication in brain networks. Recent public release of high-quality invertebrate and mammalian connectomes heralds new opportunities to study the principles underlying information transfer in nervous systems. Understanding these principles will be crucial to predicting the effects of lesions and focal brain stimulation as well as advancing knowledge of behavior and cognition (7).

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