Abstract

Introduction
Brain-to-brain transfer of information has been illustrated between a pair of rats. We evaluate the scientific validity of this study.

Short communication
First, the rats receiving the electrical stimulation were performing at 62% to 64% correctness, when chance was 50% correctness using one of the two discrimination paradigms, tactile or visual. This level of performance is not sustainable without being imbedded within a behavioural paradigm that delivers reward periodically. Second, we estimated that the amount of information transferred between the rats was 0.004 bits per second employing the visual discrimination paradigm and 0.015 bits per second employing the tactile discrimination paradigm. The reason for these low transfer scores (i.e. rates that are 1 to 2 orders of magnitude lower than that transferred by brain–machine interfaces) is that overall the rats were performing close to chance. Nevertheless, based on these results, Pais-Vieira et al. have suggested that the next step is to extend their studies to multiple brain communication.

Conclusion
We would suggest that the information transfer rate for brain-to-brain communication be enhanced before performing such an experiment. Note that the information transfer rate for human language can be as high as 40 bits per second.

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Introduction
Brain-to-brain communication has been declared between two rats (each located on different continents) trained to respond in a skinner box as published by Pais-Vieira, Lebedev, Kunicki, Wang, and Nicolelis in ‘Nature’, Scientific Reports.1 As one of the rats (i.e. the sensory-discriminating rat) selected a bar to press (or a nose poke) based on a two-choice visual (or tactile) discrimination, a second rat (i.e. the electrically-stimulated rat) was sent electrical stimulation pulses triggered by the neurons of the neocortex of the first rat. The cortical trigger signal originated from many dozens of units residing in the sensorimotor cortex of a rat. The units responded differentially depending on which of the two stimuli was to be selected by the ‘sensory-discriminating’ rat. The trigger signal varied according to the choice made by the sensory-discriminating rat such that selection of one target delivered a train of electrical pulses to the ‘electrically-stimulated’ rat while the selection of the other target delivered one pulse. In short, the electrically stimulated rat was required to make a binary choice between the presence and absence of a train of electrical stimulation delivered to its neocortex. This paper discusses the brain-to-brain interface for real-time sharing of sensorimotor information.

Short communication
The authors have referenced some of their own studies in this short communication. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies.

That animals can detect trains of electrical currents delivered to the brain has been known for over 100 years (as reviewed by Doty). Previous to the study of Pais-Vieira and colleagues, it was shown that signals recorded from the brain can be transformed into an electrical signal and delivered back to the brain to affect behaviour.1 What is new in the study of Pais-Vieira et al.1 is that the transmission of such a signal is being conveyed between the brains of two animals. The difference between whether electrical stimulation delivered to a brain is being triggered by the brain of a rat or by a computer, however, is questionable.

Nevertheless, we address the scientific validity of the experiments of Pais-Vieira et al.1 First, the sensory-discriminating rats were trained to discriminate between a pair of visual stimuli to achieve a performance of 95% correctness, while the electrically-stimulated rats were trained to discriminate between a train and no-train of electrical pulses to attain a performance of 79% correctness. After inter-cortical signal transmission between a sensory-discriminating rat and an electrically-stimulated rat, the electrically-stimulated rats performed at 64% correctness on average (Figure 2B of Pais-Vieira et al.1; a similar performance rate (i.e. 62%) was found with the rats performing a tactile discrimination task, Figure 4B of Pais-Vieira et al.1). Note that animals working at 64% correctness...
(or less) on a two-choice task are barely trained and such behaviour is unsustainable in the absence of additional reward by way of interleaved trials to maintain the performance.

Second, we ask how much information is being transferred from brain-to-brain in the study of Pais-Vieira et al. After performing the calculation using a variation of Shannon’s formula and comparing it to known transfer values, it was found that the transmission rates were more than 1 to 2 orders of magnitude below what is commonly transferred by brain-machine interfaces (Figure 1, cf. left values). The transmission rates were 0.015 bits per second and 0.004 bits per second, respectively, for the transfer of tactile-to-brain and visual-to-brain information. This translates into a yes/no response once every 1.1 to 4.2 minutes. One reason for these low scores is that when an animal is operating near chance the information transfer rate becomes negligible.

Pais-Vieira and colleagues have proposed that their next goal is to demonstrate multiple-brain communication. Clearly brain-to-brain communication needs improvement before it can rival more conventional communication systems. A human being would be deemed severely mentally retarded if he communicated at 0.004 to 0.015 bits per second since people are known to communicate at information transfer rates of up to 40 bits per second (Figure 1, cf. right values including a value for an iPad).

To appreciate the power of a normal brain connected to the body regarding language production, Birbaumer et al. found that a paralysed patient using signals from the brain to operate a speller required 16 hours of time to produce one short paragraph of text, something that would take a neurologically-intact person minutes to compose.

Some might object that making comparisons across different tasks using Shannon’s information theory is not valid, since the studies being compared are so varied given their many different levels for chance performance. But without such a systematic comparison, one cannot do any serious science. We are hopeful that more effort will be made by practitioners of systems neuroscience to create a metric superior to that of Shannon’s, although communication companies have no problem using this metric by which to charge their customers.

Finally, much is made of the idea that the signal between the rats was transmitted trans-continentally between Duke University and Natal, Brazil. This type of sensationalism was promulgated previously by the same group followed by silence from the scientific community in peer-reviewed journals. Billions of individuals routinely communicate with colleagues, friends, and family situated throughout the world using various internet devices that transmit vastly more information than has been illustrated with transcontinental transmission of any brain-to-machine device including brain-to-brain communication as discussed. The Internet is not the rate-limiting step in brain-to-brain or brain-to-device communication. Extracting sufficient information from the brain remains the bottleneck.

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So how does one establish an interface between brain and device or between brain and brain that approaches something like human language? We all know that learning a human language requires years of practice by a child so that the language memory of the brain can be programmed\(^9\)\(^-\)\(^11\) to eventually enable the rapid writing of a scientific paper or novel, for example. At the moment, the neural mechanism utilised to generate language has not been worked out\(^12\). Some practitioners of brain–machine interfaces have proposed that neural plasticity might be a solution to enhancing information transfer\(^12\). But even here understanding the process that mediates the plastic changes of the brain during learning has not gone much beyond the notions of Donald Hebb\(^14\).

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### References


## Conclusion

Clearly, many fundamental questions need to be answered to assist practitioners of brain–machine interfaces in extracting more information from the brain to control external devices.


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