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The application of printed circuit board technology for fabrication of multi-channel micro-drives

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Abstract

A modular multichannel microdrive ('hyperdrive') is described. The microdrive uses printed circuit board technology and flexible fused silica capillaries. The modular design allows for the fabrication of 4–32 independently movable electrodes or 'tetrodes'. The drives are re-usable and re-loading the drive with electrodes is simple. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Although it has been known for quite some time that information is embedded in the complex discharge patterns of neuronal ensembles, experimental approach to multisite, multiple single neuron recording technology is quite recent. With the introduction of 'tetrode' recording and cluster cutting methods (Recce and O'Keefe, 1989; Buzsáki et al., 1992; Wilson and McNaughton, 1993, 1994; Gray et al., 1995; Csicsvari et al., 1998) and the availability of miniature, direct multisite neuronal probing it is increasingly accessible for the neuroscientists to study neural interactions in relation to behavior (Wilson and McNaughton, 1994; O'Keefe and Burgess, 1996; Czurkó et al., 1999; Csicsvari et al., 1999; Eichenbaum et al., 1999; Nicolelis et al., 1997; Hampson et al., 1999). Fabrication of microdrives typically requires sophisticated machinery and skills. Although drives are also available commercially (David Kopf Instruments, Tujunga, CA; Alpha Omega Engineering, Nazareth Illite, Israel), they are quite costly and they lack the flexibility often needed for various experimental designs.

Here we describe the application of printed circuit board (PCB) technology for the fabrication of multichannel micro-drives. The new design method results in solid, low cost, sufficiently small and importantly, light weight micro-drives for extracellular single-unit, or multiunit tetrode recordings.

2. Materials and methods

The drive is fabricated from PCB modular elements, brass screws and nuts, brass spacers, and silica tubes. Fig. 1 shows a close-up view of one of the drives. A #00–90″ Brass Round Head Screw (J.I. Morris Co., Southbridge, MA) is held by 2 PCBs (boards 2 and 3). The distance of the individual PCBs is determined by the length of the brass spacers (3M Board Mount Interconnect Products; DigiKey Corp., MN). Both short (0.545″) and long (1.245″) spacers are used. The length of the spacers and screws can be custom-cut depending on the experimental conditions. Parallel to the screw, a short brass spacer prevents the hexagon-shape brass nuts from rotation, thus forcing it to move

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either up or down. The final critical part of the drive is a flexible silica capillary. The flexible fused silica capillary (75 and 153 μm inner and outer diameters, respectively; Polymicro Techologies, Phoenix, AZ) that ultimately contains the micro-wire(s) is glued to one side of the hex nut. For gluing we used a tiny drop of Loctite Superattak Gel (universal instant adhesive) but any rapid epoxy glue can be used. Four to six long spacers hold all PCBs (Fig. 2) rigidly. Similar long spacers are used to hold the 'electrode guiding grid' as well (Fig. 3). During surgery additional brass rods are soldered to the drive whereas the bottom ends are embedded in the acrylic headstage. Boards 1 and 6 are optional. They can give additional support for the screws but according to our experience the drive works adequately without them.

Fig. 2 shows the top view of two distinct versions of 6 boards used for the fabrication of the micro-drives. Fig. 2A demonstrates a conventional circular arrangement using 12 screws. This circular arrangement is the usual arrangement for the microelectrode driving screws in existing microdrive designs. The advantage of this arrangement is that the microelectrodes are easily collected to the electrode guiding grid as they are equidistant from the centre of the drive. Fig. 2B shows the modular arrangement, the largest module with 32 independently movable drives. A module element consists of four screws, i.e. four movable electrode guides. The modular design provides flexibility for the experimenter to choose the adequate size and/or number of modules for a given application. Using all 32 drives with tetrode electrodes allows for recordings from 128 wires. This arrangement is convenient with linear type of micro-connectors (e.g. 0.025″ Centerline Nano Connectors from Omnetics Connector Corp., East Minneapolis, MN, USA; 0.050″ Grid Double Row

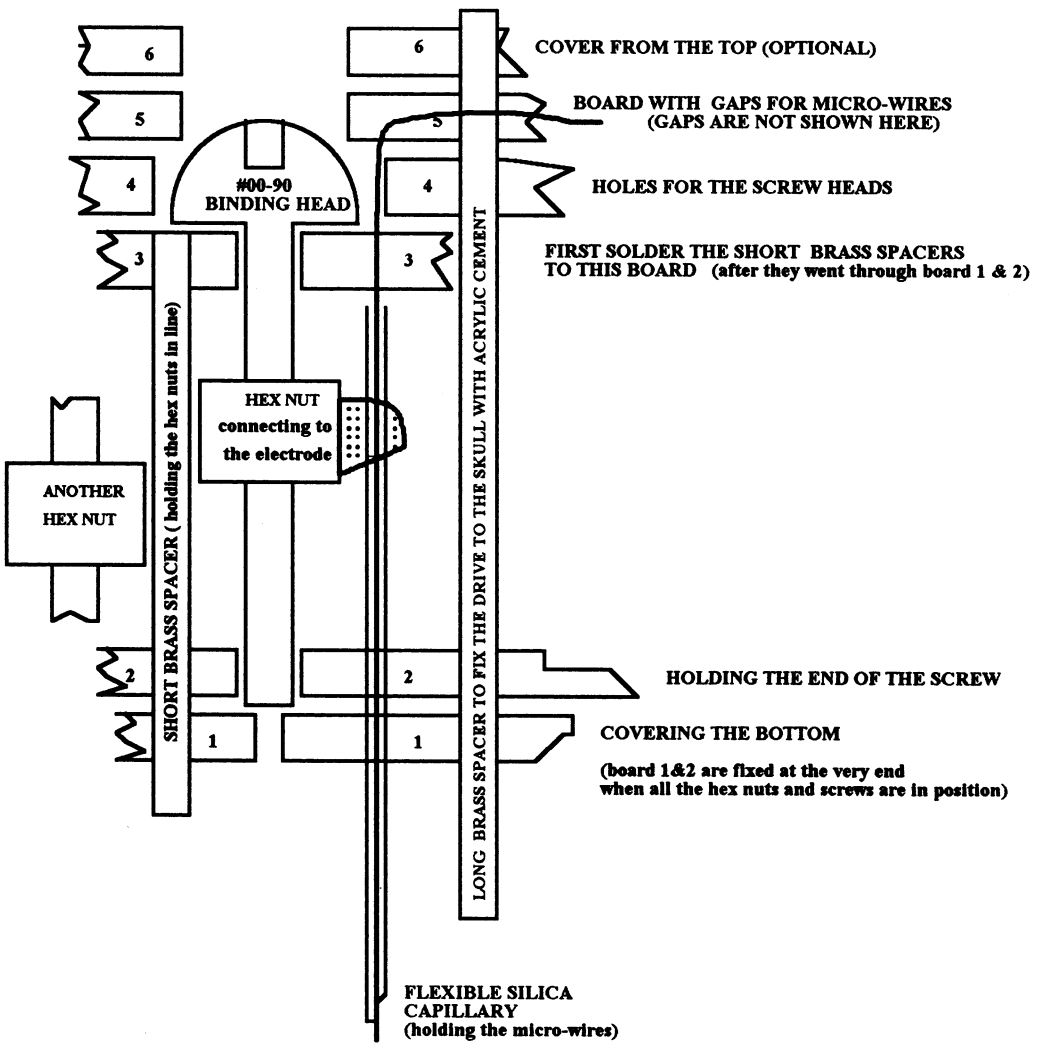

Fig. 1. Schematic side view of one machine screw surrounded by six PCB boards in a PCB fabricated micro-drive. Parallel to the screw a short brass spacer holds two hexagon nuts in line, so by turning the screw only the hex nut is moving up and down. A flexible fused silica capillary is glued to one empty side of the hex nut. The silica capillary contains the micro-wire for electrophysiological recording. The long brass spacer is holding the whole drive together through all the six boards.

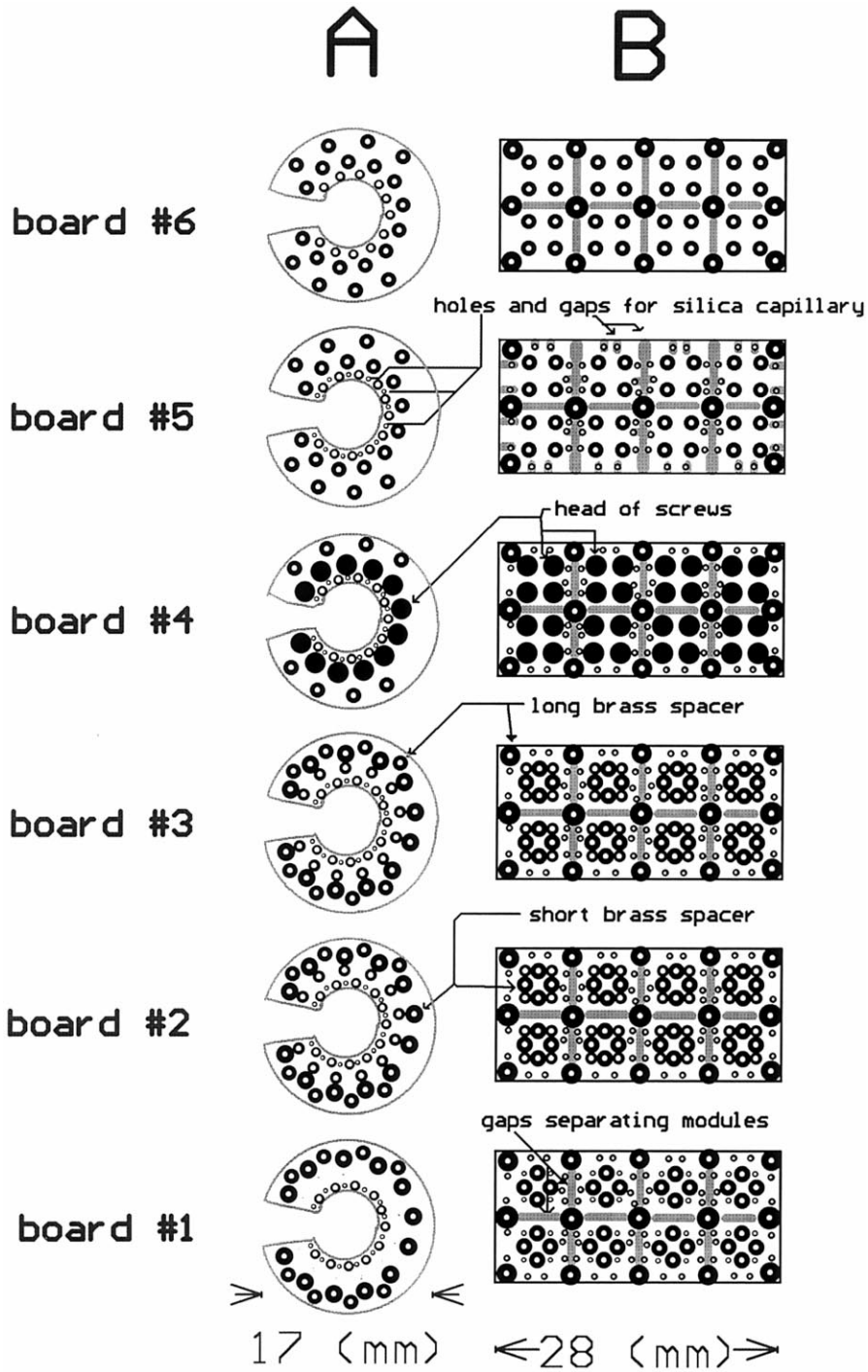

Fig. 2. Top view of the six PCB boards two distinct versions of the micro-drives. (A) A conventional circular arrangement of 12 screws. Part (B) shows a modular arrangement with 32 screws that means eight modules with four screws each. The gray lines in B, represent the gaps between the modules. The black circles are holes with copper trace material around. The big black dots in board four are holes for the head of screws.

Interconnects from Mill-Max Manufacturing Corp., Oyster Bay, NY). We tested this kind of drives most extensively. The eight screw modul was convenient for us for routine hippocampal tetrode recordings (Fig. 5).

Computer-controlled precise drilling is essential for the proper alignment of the holes in adjacent boards. The size of the small holes allows for friction fitting the spacers, which in turn are soldered to the copper plates of the board. The exact penetration sites of the electrodes are determined by a guiding cannula, fabricated from stainless steel tubes or the 'electrode guiding grid'.

Fig. 3 demonstrates some possible arrangements for the 'electrode guiding grid'. The use of flexible fused silica capillaries containing the micro-wires allows for

various 2-dimensional arrangements. An obvious advantage of the guiding grid is that the position and distance of the recording electrodes are known to the experimenter. The 'guiding grids' are also made by PCB technology but from a 3 mm-thick board. The center part of the 'guiding grids' contains the small holes for the silica capillaries, whereas the two side holes accept brass spacers for support. The bottom part of the board is inserted into a cavity in the skull so that the electrodes just touch the brain surface. The sculpted profile can help the electrode implantation. This profile can be made by the manufacturer of the board or by the experimenter and the exact dimensions are depend on the given experiment.

After the microdrive is assembled, the silica tubes are loaded with the recording electrodes. Either 50 μm single wires or tetrodes made from 12.5 μm nichrome wires (Gray et al., 1995), are pushed through the silica capillaries under microscopic control. The upper end of the wires are cleaned and soldered to a third PCB (Fig. 4). This board has prefabricated holes for a high density 37-pin single row nano connector (Omnetics Connector Corp.) as well as raws of 4 holes for accepting the tetrode wires. The soldering was done by a microsolder under the stereo microscope. Alternatively the microwires can be glued to the connector by a tiny drop of nickel print or silver print (GC electronics, Rockford, IL). A fully assembled eight screw drive is shown in Fig. 5. This means 32 channels with tetrode electrodes that could be handled by a single Omnetics connector.

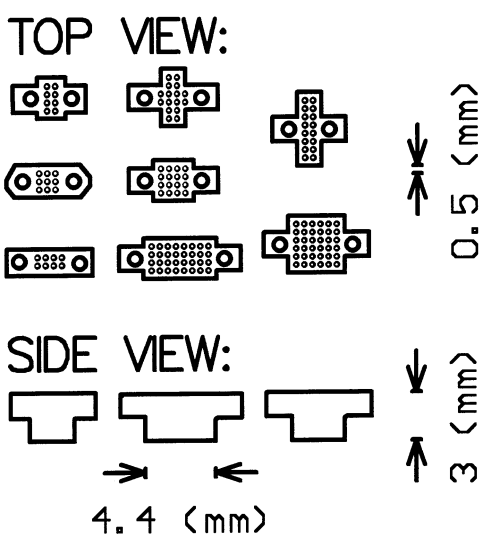

Fig. 3. Various arrangements of the 'electrode guiding grids' that collect the flexible fused silica capillaries above the brain surface. Top view: The big holes on the side are holes for the long brass spacers. The small holes in the middle are 0.2 mm in diameter and they are 0.5 mm from each other. On this PCB there is no copper trace material around the holes. Side view: Demonstrates the 3 mm thickness of this PCB. The sculpted profile can help the electrode implantation.

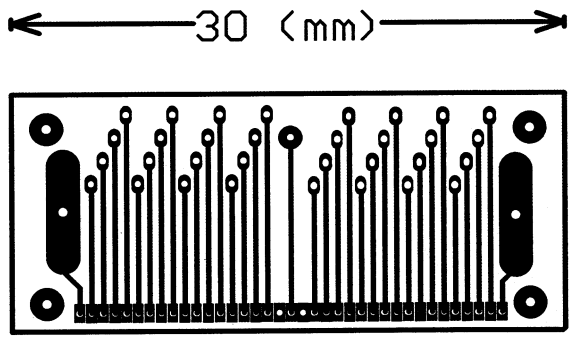

Fig. 4. This PCB has prefabricated holes for a high density 35-pin Omnetics connector as well as raws of 4 holes for accepting the tetrode wires.

We assembled some 32 screw drive modules too. The critical part assembling the 32 screw drive board as one piece is, collecting flexible fused silica capillaries to the guiding grid. It is important not to bend the capillaries coming from the far sides too much. From our experience, the distance, between the drive board and the electrode guiding grid, should be at least 3 cm. This results a 5 cm high drive without the connectors, that is quite big for chronic implantation on rats. Alternatively one can separate the 32 screw drive board to smaller modules and arrange them in angle, the way not to bent the flexible fused silica capillaries too much, and assem-

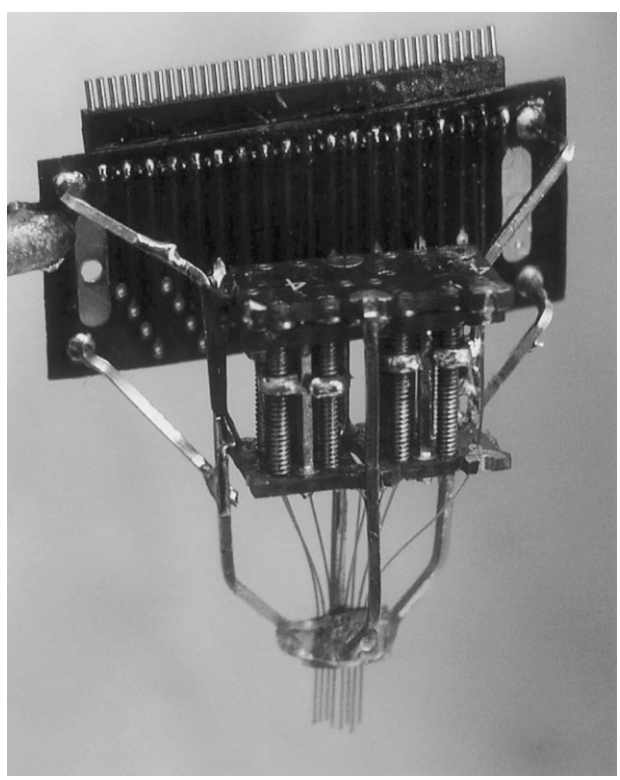

Fig. 5. Photo-image of an eight screw drive that can be loaded with tetrodes resulting in a 32-channel micro-drive. Note the micro-connector and the additional PCB board for tetrode connection.

ble a single drive from multiple module boards, that is not that high. A similar way is suggested when multiple penetration sites are required for the experiment.

Before chronic implantation an additional brass spacer is soldered parallel to the others that extends above the whole drive. This spacer is grabbed by the stereotaxic positioner at the surgical implantation and was cut afterwards. During the surgical implantation, first several #000–120 machine screws were tapped into the skull to serve as anchors for the acrylic. Above the target area a hole was drilled into the skull and the dura was cut under the dissection microscope. The electrode assembly was lowered and the exposed brain surface and the electrodes, the extending silica capillaries together with the electrode guiding grid was covered with warm (56°C) mixture of paraffin:paraffin oil (1:1). At room temperature this mixture hardens, so it protects the electrode assembly but also helps in the smooth movement of the capillaries. Later several layers of acrylic were applied to the skull, so the electrode guiding grid with the bar spacers are embedded in acrylic. The microdive and head connector were also protected by a cone-shaped carton cylinder.

The drive can be reused as only the bar spacers at the electrode guiding grid are embedded in acrylic. The acrylic can be dissolved (in chloroform) or the guiding grid and spacers can be replaced. The drive have to be reloaded by new capillaries and electrodes.

Further illustrations and manufacturer resources are available at http://cortex.pote.hu/neuronet.html. For GERBER and NC drill files contact imre@cortex.pote.hu.

3. Discussion

We described the fabrication of a simple, flexible, modular microdrive for multiple site recordings of extracellular unit activity in small animals. A special effort was made to reduce the size and weight of the drive so that they can be used for small animals such as rats and mice. Multiple drives can be placed close to each other in larger animals.

Several previous microdrives have been described earlier (Ainsworth and O'Keefe, 1977; Eichenbaum et al., 1977; Reitboeck, 1983; Kubie, 1984; Jaeger et al., 1990; Mountcastle et al., 1991). However, most of those drives were designed to move one or several electrodes simultaneously. Unit isolation from multiple site requires independent positioning of the recording wires (Reitboeck, 1983; Wilson and McNaughton, 1993; Wilson and McNaughton, 1994). Multiple microelectrode positioners are available commercially (David Kopf Instruments; Alpha Omega Engineering). However, they are expensive and not always applicable for freely moving small animals.

The micropositioner described here is not only simple but has the flexibility needed in most electrophysiological laboratories. This was made possible due to the application of PCB technology and the use of flexible fused silica capillaries. These drives have been tested for recording ensembles of hippocampal unit activity in both rats and mice (Czéh et al., 2000; Hirase et al., 2000; Szabó et al., 2000).

References

Ainsworth A, O'Keefe JA. Lightweight microdrive for the simultaneous recording of several units in the awake, freely moving rat. J Physiol (Lond) 1977;269(1):8P–10P.

Buzsáki G, Horváth Z, Urioste R, Hetke J, Wise K. High-frequency network oscillation in the hippocampus. Science 1992;15: 256(5059):1025–7.

Csicsvari J, Hirase H, Czurkó A, Buzsáki G. Reliability and state dependence of pyramidal cell-interneuron synapses in the hippocampus: an ensemble approach in the behaving rat. Neuron 1998;21:179–89.

Csicsvari J, Hirase H, Czurkó A, Mamiya A, Buzsáki G. Oscillatory coupling of hippocampal pyramidal cells and interneurons in the behaving rat. J Neurosci 1999;19:274–87.

Czéh B, King C, Harris K, Buzsaki G. Network patterns in the hippocampus of the behaving mouse. Soc Neurosci Abstr, 2000.

Czurkó A, Hirase H, Csicsvari J, Buzsáki G. Sustained activation of hippocampal pyramidal cells by 'space clamping' in a running wheel. Eur J Neurosci 1999;11:344–52.

Eichenbaum H, Pettijohn D, Deluca AM, Chorover SL. Compact miniature microelectrode-telemetry system. Physiol Behav 1977;18(6):1175–8.

Eichenbaum H, Dudchenko P, Wood E, Shapiro M, Tanila H. The hippocampus, memory, and place cells: is it spatial memory or a memory space? Neuron 1999;23(2):209–26.

Gray CM, Maldonado PE, Wilson M, McNaughton B. Tetrodes markedly improve the reliability and yield of multiple single — unit isolation from multi-unit recordings in cat striate cortex. J Neurosci Methods 1995;63:43–54.

Hampson RE, Simeral JD, Deadwyler SA. Distribution of spatial and non-spatial information in dorsal hippocampus. Nature 1999;402(6762):610–4.

Hirase H. Leinekugel X, Czurko A, Csicsvari J, Buzsaki G. Correlation of firing rates of hippocampal neurons during sleep and awake activity in behaving animals. Soc Neurosci Abstr, 2000.

Jaeger D, Gilman S, Aldridge JW. A multiwire microelectrode for single unit recording in deep brain structures. J Neurosci Meth 1990;32:143–8.

Kubie JL. A driveable bundle of microwires for collecting single-unit data from freely-moving rats. Physiol Behav 1984;32:115–8.

Mountcastle VB, Reitboeck HJ, Poggio GF, Steinmetz MA. Adaptation of the Reitboeck method of multiple microelectrode recording to the neocortex of the waking monkey. J Neurosci Meth 1991;36:77–84.

Nicolelis MA, Ghazanfar AA, Faggin BM, Votaw S, Oliveira LM. Reconstructing the engram: simultaneous, multisite, many single neuron recordings. Neuron 1997;18(4):529–37.

O'Keefe J, Burgess N. Geometric determinants of the place fields of hippocampal neurons. Nature 1996; 30, 381(6581):425–8.

Recce ML, O'Keefe J. The tetrode: a new technique for multiunit extracellular recording. Soc Neurosci Abstr 1989;15:1250.

Reitboeck HJ. A 19-channel matrix drive with individually controllable fiber micro-electrodes for neurophysiological applications. IEEE Trans Syst Man Cybern 1983;113:626–83.

Szabó I, Czurkó A, Mathé K. Advanced recording technology for hippocampal multiple unit experiments. Soc Neurosci Abstr, 2000.

Wilson MA, McNaughton BL. Dynamics of the hippocampal ensemble code for space. Science 1993;261:1055–8.

Wilson MA, McNaughton BL. Reactivation of hippocampal ensemble memories during sleep. Science 1994;265:676–9.