Cellugyrin, a Novel Ubiquitous Form of Synaptogyrin That Is Phosphorylated by pp60c-src*

Roger Janz and Thomas C. Südhof‡

From the Department of Molecular Genetics and Howard Hughes Medical Institute, The University of Texas Southwestern Medical Center, Dallas, Texas 75235

Synaptogyrin is an abundant membrane protein of synaptic vesicles containing four transmembrane regions and a C-terminal cytoplasmic tail that is tyrosine phosphorylated. We have now identified a novel isoform of synaptogyrin called cellugyrin that exhibits 47% sequence identity with synaptogyrin. In rat tissues, cellugyrin and synaptogyrins are expressed in mirror image patterns. Cellugyrin is ubiquitously present in all tissues tested with the lowest levels in brain tissue, whereas synaptogyrin protein is only detectable in brain. Transfection studies in COS cells demonstrated that both cellugyrin and synaptogyrin are tyrosine phosphorylated in vivo by pp60c-src, and experiments with recombinant proteins showed that pp60c-src phosphorylates the cytoplasmic tails of these proteins in vitro. Cellugyrin and synaptogyrin co-localize when transfected into COS cells but are differentially distributed in brain, the only tissue where both proteins are detectable. Our data suggest that the synaptic vesicle protein synaptogyrin is a specialized version of a ubiquitous protein, cellugyrin, with the two proteins sharing structural similarity but differing in localization. This finding supports the emerging concept of synaptic vesicles as the simplified and specialized form of a generic trafficking organelle. The conserved tyrosine phosphorylation of cellugyrin and synaptogyrins suggests a link between tyrosine phosphorylation via pp60c-src and membrane traffic.

Synaptic vesicles represent specialized secretory organelles that store neurotransmitters in nerve terminals. Their function is to release neurotransmitters by fusing with the presynaptic plasma membrane during exocytosis. Synaptic vesicle exocytosis is a highly regulated Ca2+-dependent process. After exocytosis, empty synaptic vesicles are recycled and reloaded with neurotransmitters. It has been shown that the protein composition of synaptic vesicles is rather simple with a limited number of major proteins (reviewed in Ref. 1). Functions for some vesicle proteins have been identified, for example essential roles for synaptotagmin and synaptobrevin in Ca2+-triggered exocytosis (2–4). Others, such as rab3A (5–7) and synapsins (8, 9), play a modulatory role. However, for several vesicle proteins no function has yet been elucidated including synaptogyrin and synaptophysin. Synaptogyrin and synaptophysins I and II (synaptoporin) are among the most abundant vesicle proteins. Synaptophysin I alone accounts for 7% of the total vesicle membrane protein (10). Synaptogyrin and synaptophysins contain four transmembrane regions with cytoplasmic N and C termini, are distantly related to each other, and are tyrosine phosphorylated on synaptic vesicles by an endogenous kinase (11–14). The tyrosine kinase pp60c-src is peripherally associated with synaptic vesicles and phosphorylates synaptophysin I in vitro (15–17). The role of this modification is not clear but it could participate in the regulation of synaptic exocytosis.

Originally synaptic vesicles were thought to be very different from other exocytotic organelles, especially exocytotic vesicles that are involved in constitutive exocytosis. This hypothesis was based on the exquisite specificity of the localization of synaptic vesicle proteins to synapses and on the unusual degree of regulation of synaptic vesicle exocytosis. However, results in recent years revealed that many vesicle proteins have closely related homologues in constitutive ubiquituous vesicular trafficking pathways. The first such protein characterized was cellubrevin, which contains a central sequence that is almost identical to that of synaptobrevin and can also be cleaved by tataus toxin, suggesting a conserved mechanism of membrane fusion in regulated and constitutive exocytotic pathways (18). Since then, isoforms of synaptophysin, rab3, and synaptotagmins have been found outside of neurons, indicating a general parallelism between Ca2+-triggered membrane traffic at the synapse and Ca2+-independent membrane traffic in all cells (19–21). For other abundant vesicle proteins like synaptogyrin, however, no corresponding homologue outside of the nervous system has been characterized, raising the question of whether there are, after all, proteins that are specific for synaptic vesicles.

We describe here the characterization of a protein, cellugyrin, that is closely related to synaptogyrin but widely expressed in non-neuronal tissues. Cellugyrin, like synaptogyrin, is tyrosine phosphorylated, suggesting a link between membrane traffic and tyrosine phosphorylation that is conserved between regulated and constitutive membrane-trafficking pathways. Our data support the notion that synaptic vesicle traffic is closely related to ubiquitous membrane-trafficking pathways with similar protein components not only in fusion but also in regulation.

EXPERIMENTAL PROCEDURES

cDNA Cloning and Construction of Expression Vectors—Homology searches identified a single class of synaptogyrin homologues in the human and mouse EST data banks. A restriction fragment (~1-kb1 HindIII/PstI fragment) from a human EST clone (IMAGE 51526 from

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† To whom correspondence should be addressed. Tel.: 214-648-5022; Fax: 214-648-6426.

1 kb, kilobase(s); EST, expressed sequence tag; GST, glutathione S-transferase; bp, base pair(s).
cellugyrin is phosphorylated by pp60^src

**RESULTS**

**Primary Structure of Cellugyrin**—To identify genes that are homologous to synaptogyrin, we used the sequence of rat brain synaptogyrin to search EST data banks for other isoforms. Only two classes of human EST sequences with significant homology to rat brain synaptogyrin were found; one class of ESTs with a high degree of homology to rat synaptogyrin (>80%) that presumably corresponds to the human ortholog of rat synaptogyrin (not shown); a second class contained a lower degree of homology to synaptogyrin (37–55% identity) that was distributed across the entire protein sequence, suggesting that the second class corresponds to a novel isoform of synaptogyrin. Since the EST data banks are thought to be nearly saturated, our results suggest that there are only two major forms of synaptogyrin in humans, the previously characterized neuronal form (12) and a novel isoform.

We employed a human EST clone corresponding to the novel isoform (IMAGE 51526) to screen a rat brain and liver cDNA library and isolated one positive clone from brain and eight from liver. The sequences of the clones were assembled into a full-length sequence with an open reading frame of 234 amino acids (Fig. 1). Because this protein is highly homologous to synaptogyrin but ubiquitously expressed in all cells tested (see below), we named the protein cellugyrin.

**Structures of Cellu-/Synaptogyrins and Synaptophysins Define Distantly Related Protein Families**—Data bank searches with the cellugyrin sequence confirmed that it is closely related to synaptogyrin (47% identity between rat synapto- and cellugyrin) and weakly homologous to synaptophysins. The overall identity between cellu-/synaptogyrins and synaptophysins is low (identities with cellugyrin: synaptophysin I = 14.5%; synaptophysin II/synaptoporin = 12%; pantophysin = 10%). Their relation becomes only apparent if one considers the overall similarity in structure and the higher homology between segments of their sequences that are related to each other in a statistically significant manner (Fig. 1). The synaptophysins are more closely related to each other than they are to cellu-/synaptogyrins, but less closely than cellugyrin is related to synaptogyrin. Together these data define two families of highly homologous proteins that are distantly related to each other.

Analysis of the cellu-/synaptogyrin and synaptophysin sequence reveals interesting similarities and differences. All of these proteins have four transmembrane regions. The transmembrane topologies of synaptophysin I and synaptogyrin were mapped biochemically, demonstrating that both N and C termini are cytoplasmic (11, 12). The sequence similarity between cellu- and synaptogyrin suggests that they have similar transmembrane topologies. The two intravesicular loops of synaptophysins and cellu-/synaptogyrins are highly conserved within each of the two protein families but exhibit no similarity between the families. The largest domains of the synaptophysin I and synaptogyrin are more closely related to each other than they are to cellu-/synaptogyrins, but less closely than cellugyrin is related to synaptogyrin. Together these data define two families of highly homologous proteins that are distantly related to each other.

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cysteines each that form an intramolecular disulfide bond within each loop (25). The first but not the second intravesicular loop of the cellu-/synaptogyrins also has a pair of cysteine residues that could potentially form intramolecular disulfide bonds similar to synaptophysins or intermolecular disulfide bonds. To test this, we analyzed the subunit structure of cellu- and synaptogyrins on nonreducing gels (data not shown). Synaptogyrin or cellugyrin did not shift to higher apparent molecular weights in the absence of reducing agents, suggesting that they are not disulfide linked to each other or to another protein. The similarity of cellu-/synaptogyrins to synaptophysins suggests that an intramolecular disulfide bond may be formed by the two cysteines in the first intravesicular loop.

RNA Blot Analysis of Cellugyrin Expression—To determine which tissues express cellugyrin, we hybridized a multitissue RNA blot with a cellugyrin probe at high stringency (Fig. 2). A single mRNA of approximately 1.7 kb was detected with abundant expression in all tissues except for low levels in testis and brain. When we reprobed the same blot for synaptogyrin, we found that the highest levels of the 4.2-kb synaptogyrin mRNA were present in brain with lower but detectable levels in several other tissues, in particular kidney (Fig. 2). In addition to the bona fide 4.2-kb synaptogyrin mRNA, the synaptogyrin probe detected in several non-brain tissues two small mRNAs that do not produce a synaptogyrin protein (see below) and whose significance is unclear. Together these data demonstrate that the cellu- and synaptogyrin mRNAs are expressed in a mirror-image pattern. Cellugyrin mRNA is ubiquitously present in all tissues tested with lowest levels in brain whereas synaptogyrin mRNA is synthesized at high levels only in brain.

Expression of Cellugyrin Protein—To test if the protein encoded by the cellugyrin mRNA is actually synthesized, we
raised an antibody to the C-terminal 57 residues of cellugyrin fused to maltose-binding protein. Immunoblots with this antibody of extracts from COS cells transfected with a cellugyrin expression vector revealed a band of the appropriate size (29 kDa) that was absent in control COS cells (Fig. 3, left two lanes in the left panels). The signal in the transfected COS cells could be blocked with a GST-fusion protein containing the C terminus of cellugyrin but not with GST alone (Fig. 3). The cellugyrin antibody did not react with synaptogyrin, and synaptogyrin antibodies did not react with cellugyrin (Fig. 3, left two lanes in the right panels). Therefore there is no immunological cross-reactivity between cellu- and synaptogyrins.

Next we investigated if rat tissues contain cellugyrin protein. Immunoblots revealed that the cellugyrin antibody reacted with a major 29-kDa protein that co-migrates with transfected cellugyrin and is present in most tissues but barely detectable in brain (Fig. 3). In addition, reactivity with several additional proteins of larger apparent molecular weight was observed. When we blocked the antibody with the GST-cellugyrin fusion protein, only the signal for the 29-kDa protein but not the signal for the other proteins was abolished, suggesting that the other immunoreactivities are nonspecific (Fig. 3, left panels, arrowheads). Addition of GST alone had no effect. Thus the 29-kDa band corresponds to cellugyrin, which is widely expressed as protein in most rat tissues except for brain. Similar blots were also probed for synaptogyrin, revealing that synaptogyrin protein was only detectable in brain but not in other tissues, not even kidney which contains significant mRNA levels (compare Fig. 3, right panels with Fig. 2). Therefore the mirror-image pattern of tissue-specific expression observed for the cellu- and synaptogyrin mRNAs blots is also found with the corresponding proteins.

Subcellular Localization of Synaptogyrin and Cellugyrin—
The sequence similarity between cellugyrin and synaptogyrin suggests related functions, whereas their differential distributions indicate that they perform these functions for different cells. To gain first insights into the subcellular localization of cellu- and synaptogyrin, we overexpressed them by transfection in COS cells and studied their localization by immunofluorescence microscopy (Fig. 4 and data not shown). In transfected COS cells, both proteins produced very similar staining
patterns, suggesting that they are localized to the same compartment. This was confirmed by double-labeling experiments of COS cells co-transfected with both proteins (Fig. 4). Although the exact localization of a protein is difficult to evaluate in overexpression studies, most of the protein stain was present in a reticular or microvesicular pattern, suggesting that the two proteins are sorted into the same compartments, which resemble those previously characterized for cells transfected with synaptophysin (26).

We next evaluated the localization of endogenous cellugyrin in tissues. Since the cellugyrin antibodies cross-react with abundant unknown proteins in most tissues (Fig. 3), it was not possible to perform immunocytochemistry. Therefore we used subcellular fractionation of rat liver and brain as a first measure of localizing these proteins. Our data show that in liver, cellugyrin is highly enriched in microsomes, a fraction that contains small vesicles, endoplasmic reticulum, and plasma membrane, but is basically absent from nuclei or mitochondria. A similar distribution was observed in brain, the only tissue in which both cellu- and synaptogyrin are detectable. Comparison

FIG. 4. Co-localization of cellugyrin and synaptogyrin in transfected COS cells. COS cells were co-transfected with cellugyrin and synaptogyrin and reacted with the rabbit cellugyrin antibody (panel A) and a monoclonal synaptogyrin antibody (panel B) followed by CY3-coupled anti-rabbit and fluorescein isothiocyanate-coupled anti-mouse secondary antibodies. Panel C depicts a superposition of panels A and B.

FIG. 5. Subcellular distribution of cellugyrin analyzed by tissue fractionation. Rat liver and brain homogenates (lane 1, total) were subfractionated using differential centrifugation into crude nuclear fractions (lane 2, P1; 600 × g pellet), crude mitochondrial fractions (lane 3, P2; 10,000 × g pellet), microsomes (lane 4, P3; 100,000 × g pellet) and cytosol (lane 5, S3; 100,000 × g supernatant). Synaptic vesicles purified by controlled pore glass chromatography from a microsomal fraction of synaptosomes (lane 6) and COS cells transfected with cellugyrin expression vector (lane 7, pCMV-Cgyr) or synaptogyrin expression vector (lane 8, pCMV-Sgyr) were also obtained. Samples were analyzed by immunoblotting for cellugyrin and synaptogyrin as indicated. Nonspecifically reacting proteins in the cellugyrin blots are labeled with arrowheads (see also Fig. 3).
of the distribution of cellu- and synaptogyrin in brain showed that they co-enrich in microsomes (Fig. 5, lane 4). However, they are localized to distinct organelles in brain. Synaptogyrin, as described previously, is highly enriched in synaptic vesicles (Fig. 5, panel C, lane 6). Cellugyrin in contrast is completely absent from synaptic vesicles (Fig. 5, panel B, lane 6), possibly because it is not expressed by neurons but by glia cells. Thus synapto- and cellugyrin are both primarily found in light membranes but in brain, cellugyrin is not present on synaptic vesicles.

Synaptogyrin and Cellugyrin Are Tyrosine Phosphorylated by pp60c-src—Previous studies showed that in synaptic vesicles, synaptogyrin and synaptophysin are tyrosine phosphorylated, and pp60c-src is associated with synaptic vesicles (14–16). This prompted us to ask if cellu- and synaptogyrin could represent a conserved family of tyrosine-phosphorylated trafficking proteins. To address this question, we co-transfected COS cells with expression vectors encoding the neuronal splice variant of pp60c-src and synaptogyrin or cellugyrin. The COS cells were then analyzed by immunoblotting with antibodies against the transfected proteins and against tyrosine phosphorylation (Anti-P-Tyr; top), synaptogyrin (middle), and pp60c-src (bottom). Positions of molecular weight standards are indicated on the right. Arrows point to the migration of pp60c-src (~60 kDa) and synaptogyrin (~30 kDa). Note that tyrosine-phosphorylated synaptogyrin is only present if pp60c-src is co-transfected with synaptogyrin.

Transfection of pp60c-src alone resulted in the appearance of a single major tyrosine-phosphorylated protein that was identified by immunoblotting as pp60c-src (Fig. 6). However, when we co-transfected synaptogyrin with pp60c-src, we observed a second tyrosine-phosphorylated protein of 29 kDa. Immunoblotting confirmed that this protein corresponded to synaptogyrin (Fig. 6). When we transfected synaptogyrin without pp60c-src, no tyrosine phosphorylation was observed. These data confirm that synaptogyrin is a tyrosine-phosphorylated protein, and demonstrate that it is a substrate for pp60c-src in vivo. To test if cellugyrin is also a substrate, we performed analogous transfection experiments with pp60c-src and cellugyrin expression vectors with virtually identical results (Fig. 7). In fact, based on signal strength, cellugyrin was a better substrate for pp60c-src than synaptogyrin. However, immunocytochemistry revealed that the transfected COS cells, the distribution of cellu- and synaptogyrin did not change as a function of tyrosine phosphorylation (data not shown).

Together these data show that cellu- and synaptogyrins are tyrosine-phosphorylated proteins that serve as substrates for pp60c-src. Inspection of the cellu- and synaptogyrin sequences reveals that there is only a single cytoplasmic tyrosine in the N-terminal region but multiple conserved cytoplasmic tyrosines in the C-terminal sequence (Fig. 1, asterisks). Based on this finding, it seems likely that pp60c-src phosphorylates the cytoplasmic tail of cellu- and synaptogyrin. We confirmed this hypothesis using recombinant maltose-binding fusion proteins.
of the C termini of cellu- and synaptogyrin and recombinant pp60<sup>src</sup>, demonstrating that the cytoplasmic tails of cellu- and synaptogyrin are substrates for this tyrosine kinase (data not shown).

**DISCUSSION**

Major progress has been made in recent years in the understanding of the structures and functions of synaptic vesicle proteins. Now most of the intrinsic membrane proteins of synaptic vesicles have been identified, and the roles of some of them in exocytosis have been elucidated (for review, see Ref. 1). One of the major results emerging from these studies was the realization that the mechanisms involved in the execution and regulation of synaptic vesicle fusion are not specific for synaptic vesicles. Instead, homologues to all of the proteins that were functionally characterized in synaptic vesicle exocytosis were found in other trafficking pathways where they may perform analogous functions. For example, a close homologue of synaptofibrin called cellubrevin appears to function in constitutive exocytosis similarly to synaptofibrin, and multiple forms of synaptotagmins are expressed in non-neuronal tissues (18, 20). An exception to the parallelism between synaptic vesicle proteins and proteins of constitutively active exocytic vesicles is synaptogyrin. This protein is one of the more abundant vesicle proteins that is present in all synaptic vesicles independent of neurotransmitter type but has no known nonsynaptic correlate. With cellubrevin, we have now described a protein that is closely related to synaptogyrin but primarily expressed outside of brain in tissues in which no synaptogyrin protein is detected. Cellu- and synaptogyrin are homologous to each other over their entire sequences and exhibit no major differences, suggesting similar functions. In addition, they are distantly related to synaptophysins, with which they may share an evolutionary ancestor. The co-expression of these distantly related protein families on the same synaptic vesicles and their coinvolvement in regulating synaptic membrane traffic, a hypothesis that is supported by the finding that Ca<sup>2+</sup> influx into neurons activates tyrosine phosphorylation (27–29). However, these observations also raise a number of questions: Does pp60<sup>src</sup> actually phosphorylate synaptogyrin? Is tyrosine phosphorylation a conserved feature of the cellu- and synaptogyrin protein family? Where are these proteins phosphorylated? We have addressed these questions by showing that synaptogyrin is effectively tyrosine phosphorylated by pp60<sup>src</sup> in transfected cells. Furthermore, we found that cellubrevin is as good a substrate for pp60<sup>src</sup> as synaptogyrin and that the cytoplasmic C termini of these proteins are substrates for pp60<sup>src</sup>. Therefore cellu- and synaptogyrins form an evolutionarily conserved protein family in vesicular membrane traffic whose members are differentially expressed but similarly tyrosine phosphorylated.

The major question now regards the function of synaptogyrin and cellubrevin. Despite extensive work on these proteins and on the synaptophysins, their distant relatives, their functions have remained elusive. Their structures and patterns of conservation suggest a role related to the vesicular membrane because a large proportion of their total sequences are devoted to transmembrane regions and their transmembrane regions are the most conserved sequences among family members. Knockout mice in synaptophysin I and in synaptogyrin are not lethal, demonstrating that these proteins are not essential for neurotransmitter release as such (30). These results together with the tyrosine phosphorylation of cellu-/synaptogyrins indicates that the role of synaptogyrin may be to regulate neurotransmitter release and that cellubrevin may have an analogous function in regulating membrane traffic in non-neuronal cells.

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**REFERENCES**

1. Sudhof, T. C. (1995) *Nature* 375, 645–653
2. Gerpet, M., Goda, Y., Hammer, R. R., Li, C., Rosahl, T. W., Stevens, C. F., and Sudhof, T. C. (1994) *Cell* 79, 717–727
3. Schiavo, G., Benfenati, F., Poulain, B., Rossetto, O., Polverino de Laureto, P., and DaasGupta, C. R. (1992) *Nature* 359, 832–835
4. Link, E., McMahan, H., Fischer von Mollard, G., Niemann, H., Sudhof, T. C., and Jahn, R. (1993) *J. Biol. Chem.* 268, 18423–18426
5. Geppert, M., Bolshakov, V. Y., Siegelbaum, S. A., Takei, K., De Camilli, P., Hammer, R. E., and Sudhof, T. C. (1994) *Nature* 369, 493–497
6. Geppert, M., Goda, Y., Stevens, C. F., and Sudhof, T. C. (1997) *Nature* 387, 810–814
7. Castillo, P. E., Janz, R., Sudhof, T. C., Tenenopoulos, T., Malenka, R. C., and Nicoll, R. A. (1997) *Nature* 388, 590–592
8. Rosahl, T. W., Spillane, D., Misssler, M., Herz, J., Selig, D. K., Wolf, J. R., Hammer, R. E., Malenka, R. C., and Sudhof, T. C. (1995) *Nature* 375, 488–493
9. Rosahl, T. W., Geppert, M., Spillane, D., Herz, J., Hammer, R. E., Malenka, R. C., and Sudhof, T. C. (1995) *Cell* 75, 661–670
10. Jahn, R., Schioler, W., Otmietz, C., and Greengard, P. (1986) *Proc. Natl. Acad. Sci. U. S. A.* 82, 4137–4141
11. Johnston, P. A., Jahn, R., and Sudhof, T. C. (1989) *J. Biol. Chem.* 264, 1268–1273
12. Stenius, K., Janz, R., Sudhof, T. C., and Jahn, R. (1995) *J. Cell Biol.* 131, 1801–1809
13. Pang, D. T., Wang, J. K., Valtorta, F., Benfenati, F., and Greengard, P. (1988) *Proc. Natl. Acad. Sci. U. S. A.* 85, 762–766
14. Baumert, M., Takei, K., Hartinger, J., Burger, P. M., Fischer von Mollard, G., Maycox, P. R., De Camilli, P., and Jahn, R. (1990) *J. Cell Biol.* 110, 1265–1294
15. Barnekow, A., Jahn, R., and Shartl, M. (1990) *Onkogene* 5, 1019–1024
16. Linstedt, A. D., Vetter, M. L., Bishop, J. M., and Kelly, R. B. (1992) *J. Cell Biol.* 117, 1077–1084
17. Hirano, A. A., Greengard, P., and Huganir, R. L. (1988) *J. Neurochem.* 50, 1447–1455
18. McMahon, H., Ushkaryov, Y. A., Link, E., Edelmann, L., Minn, T., Niemann, H., Jahn, R., and Sudhof, T. C. (1993) *Nature* 364, 346–349
19. Baldini, G., Scherer, P. E., and Lodish, H. F. (1995) *Proc. Natl. Acad. Sci. U. S. A.* 92, 4284–4288
20. Li, C., Ullrich, B., Zhang, J. Z., Anderson, R. G. W., Brosse, N., and Sudhof, T. C. (1995) *Nature* 375, 594–599
21. Laube, R. E. (1994) *Differentiation* 56, 163–171
22. Anderson, S., Davis, D. N., Dahlback, H., Jornvall, H., and Russell, D. W. (1989) *J. Biol. Chem.* 264, 8222–8229
23. Martinez, R., Mathey-Prevot, B., Bernards, A., and Baltimore, D. (1987) *Science* 237, 411–415
24. Gorman, C. (1985) *DNA Cloning*, Vol. III, pp. 143–190, IRL Press, Oxford
25. Johnston, P. A., and Sudhof, T. C. (1990) *J. Biol. Chem.* 265, 8869–8873
26. Johnston, P. A., Cameron, P. L., Stuckenbrok, H., Jahn, R., de Camilli, P., and Sudhof, T. C. (1990) *EMBO J.* 9, 2863–2872
27. Lev, S., Moreno, H., Martinez, R., Canoll, P., Peles, E., Musacchio, J. M., Plowman, G. D., Rudy, B., and Schlessinger, J. (1995) *Nature* 376, 737–745
28. Rasanesco, G., Qi, H., Thomas, S. M., Brugge, J. S., and Hagleous, S. (1995) *Neuron* 15, 1415–1425
29. Delia Rocco, G. J., Viesen, T. V., Daaka, Y., Luttrel, D. K., Luttrel, M. M., and Lefkowitz, R. J. (1997) *J. Biol. Chem.* 272, 19125–19132
30. McMahan, H. T., Bolshakov, V. Y., Janz, R., Hammer, R. E., Siegelbaum, S. A., and Sudhof, T. C. (1996) *Proc. Natl. Acad. Sci. U. S. A.* 93, 4760–4764

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<sup>2</sup> R. Janz and T. C. Sudhof, unpublished observation.
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