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Trafficking and Adaptive Intelligence of AMPA Receptors: A Bibliometric and Biochemical Review of Synaptic Plasticity

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Abstract

Synaptic plasticity is the cellular basis of learning, memory and adaptation. Among the regulatory mechanisms of plasticity, trafficking of AMPA receptor subunits (AMPARs) is relatively important, and it determines how many glutamate receptors are located at excitatory synapses and what their function is. AMPAR trafficking is considered to be the biochemical basis of synaptic signaling and cognition and adaptive intelligence in this review. By summarizing the process of NMDAR insertion, lateral diffusion, synaptic anchoring, endocytosis and recycling, as well as phosphorylation and interactions among NMDARs, GluA1/GluA2 subunits, CaMKII, PKA, PKC, PSD-95, PICK1, GRIP and TARPs, it is hoped that the connections between these processes and long-term potentiation and long-term depression, learning and memory, cognitive flexibility and vulnerability to neurological and psychiatric diseases will be explored. A bibliometric module will be built in R with the help of the bibliometric package to analyze the development trends of the data, keyword co-occurrence and theme changes, etc. Finally, this paper also provides cross-disciplinary suggestions for NeuroAI, neuroengineering, brain-computer interfaces, computational neuroscience, psychology, etc. AMPAR trafficking is a molecular model of adaptation, and the cause of behavior is not yet known in terms of receptor dynamics.

Keywords

AMPA Receptor Trafficking, Synaptic Plasticity, Long-Term Potentiation, Long-Term Depression, Learning and Memory, Bibliometrics

1. Introduction

The ability to learn from experience is related to the nervous system's ability to

alter the strength and arrangement of synapses. After learning that high-frequency stimulation can extend the duration of synaptic transmission in the hippocampus, long-term potentiation has been investigated in detail to determine the basic cellular mechanism of memory formation [1] [2]. On the other hand, prolonged depression can reduce the effectiveness of synapses or even modify them. Together, LTP and LTD allow neural circuits to encode experience while maintaining flexibility and adaptivity [3]. How to convert transient patterns of neural activity into permanent alterations in synaptic function remains a fundamental problem in neuroscience and psychology and is also attracting attention in artificial intelligence.

AMPA receptors in the excitatory synapses of the mammalian brain are associated with fast synaptic transmission. Their number and biophysical characteristics at the postsynaptic membrane are the reasons for different magnitudes of excitatory postsynaptic currents. AMPARs are tetrameric ion channels that consist of four GluA1-GluA4 subunits, and among them, GluA1 and GluA2 have received more attention in hippocampal plasticity. Unlike a static synaptic component, AMPARs are constantly being inserted into, removed from, and redistributed within the cell membrane of neurons. This trafficking is used to alter the number of receptors on synapses according to different activities. To enhance a synapse, one can increase the number of AMPA receptors at or near the postsynaptic density; otherwise, the number of AMPA receptors will be lowered because some have been internalized and recycled or broken down.

In this review, "adaptive intelligence" is defined as the capacity of a biological or artificial system to modify future responses on the basis of prior activity, environmental feedback, or internal state. This definition includes three measurable components: experience-dependent updating, in which previous activity changes subsequent processing; stability-flexibility balance, in which useful information is stored while outdated associations can be revised; and context-sensitive behavioral or computational adjustment, in which the system changes its output when task demands or environment change. In biological systems, these components can be studied across molecular, synaptic, circuit, and behavioral levels. At the synaptic level, AMPAR trafficking provides one mechanism trough which activity-dependent biochemical events can alter synaptic efficacy and thereby contribute to adaptive updating.

Therefore, the adaptive intelligence is used not as a broad claim that AMPAR trafficking alone explain intelligence, but as an interdisciplinary framework for connecting molecular plasticity to learning, memory, cognitive flexibility, and biologically inspired models of adaptive computation. In this paper, AMPAR trafficking is to be used in the study of biological signals and adaptation intelligence. In line with the theory of synaptic neuroscience, adaptive intelligence is the ability of neural circuits to modify the strength of synapses in response to different activity levels and thus change their function. Adaptability is a change in the molecules of synaptic plasticity and therefore changes in AMPAR transport. Changes in the biology of all of these layers are thus realized at all times: gene expression,

synaptic transmission, circuit dynamics, development and social environment, etc. AMPAR trafficking is not about cognition: rather, it is a system to study how changes in the pattern of activity affect synaptic strength and changes in circuit calculation and the modification support for learning.

The three sections of this paper are biochemistry, systems and computation. First, it explains the biochemical basis of AMPAR trafficking, including the mechanisms of receptor insertion, endocytosis, recycling, phosphorylation and synaptic localization. It also shows how the above processes promote LTP and LTD, memory, cognition and disease. Third, this review puts forward a bibliometric strategy to evaluate the development of AMPAR trafficking research and how it is now related to NeuroAI, neuroengineering, computational neuroscience, psychology, etc. Both biochemical and bibliometric methods are appropriate for an interdisciplinary review of the literature; thus, both the reasons behind the research and the structure of the research field can be covered.

2. Biochemical Basis of AMPA Receptor Trafficking

The movement of AMPA receptors is irregular in all kinds of situations, and a certain number of functional receptors near the excitatory synapse are regulated by a cycle of exocytosis, lateral diffusion, and endocytosis [4]. The process starts with the assembly and modification of receptors in the endoplasmic reticulum and Golgi apparatus, followed by transport along the dendrites and delivery to membrane areas. Mature synapses do not have a fixed AMPARs. They undergo exocytosis, lateral diffusion, trapping by synaptic scaffold proteins, clathrin-mediated endocytosis, recycling through endosomal pathways, and degradation. This dynamic exchange supports both basal synaptic transmission and activity-dependent plasticity.

The Composition of AMPAR Subunits affects trafficking and function. GluA1-containg receptors have an activity-dependent addition of LTP; whereas GluA2-containing receptors change calcium permeability and undergo endocytosis [5]. In short, the edited GluA2 subunits cannot be activated by calcium and therefore reduce the amount of calcium that enters neurons. Receptors lacking GluA2 are calcium-permeable and can be expressed transiently in some types of plasticity; however, the degree and function of this insertion vary according to the different cells, different stages of development, and under various stimulus conditions. The receptor subunits have different C-terminal domains in the cytoplasm and therefore recruit different trafficking factors and kinases.

Synaptic localization of AMPARs is influenced by postsynaptic density scaffolds. PSD-95 is the major scaffolding protein for glutamate receptors and other signal complexes in the postsynaptic density of excitatory synapses [6]. AMPARs do not directly bind with high affinity to PSD-95; rather, the accessory protein TARP is needed to link AMPARs with PSD-95 and form a synapse. Stargazin is one of the most studied TARPs and can modulate AMPAR gating, pharmacology, surface expression and synaptic localization. Phosphorylation of Stargazin can

increase its binding to PSD-95 and increase the number of AMPA receptors by changing the stability of these receptors through chemical signals.

AMPAR-interacting proteins also regulate subunit-specific trafficking [7]. GRIP and ABP are associated with the C-terminal tail of GluA2 and affect receptor stability and trafficking. PICK1 is related to GluA2 and the endocytosis and LTD-related trafficking of receptors. The amount of GRIP-mediated retention and PICK1-associated internalization determines whether the GluA2-containing receptor is still at the synapse or has been taken up by endosomes. They are not single switches but the parts of a large-scale network, which include small GTPases, actin reorganization, endosomal sorting proteins, postsynaptic scaffolds and so on.

Phosphorylation is another way to regulate the trafficking of AMPARs [8]. GluA1 phosphorylation at serine 831 is associated with CaMKII and PKC signaling and can increase channel conductance. GluA1 phosphorylation at serine 845, regulated by PKA, is associated with receptor open probability, extra synaptic receptor availability, and activity-dependent insertion. Although phosphorylation is often linked to LTP, the effects of different kinds of phosphorylation vary with development time, brain areas, stimulation history and associated receptor proteins. Dephosphorylation of phosphatases such as PP1 and calcineurin causes LTD and loss of receptors.

NMDARs are the main upstream signals for AMPAR trafficking [8]. Many kinds of LTP lead to postsynaptic depolarization and thus increase the influx of calcium by removing the magnesium block on NMDARs. An increase in calcium will boost the activity of CaMKII and other signal transduction pathways to increase the phosphorylation, exocytosis and synaptic stability of AMPA receptors. LTD is a small increase or extension of calcium that increases the activity of phosphatases, leading to dephosphorylation and endocytosis of AMPARs. A simple but convenient model of calcium-dependent bifurcation is that the time and place of the calcium signal determine whether a synapse is strengthened or weakened [9].

Receptor insertion often occurs first at extra synaptic sites, after which AMPARs move laterally into synapses and become trapped by scaffold interactions. There may be direct synaptic exocytosis under some circumstances. Endocytosis usually takes the form of clathrin-mediated endocytosis, and it is dynamin-dependent vesicle formation. Intracellular receptors can be taken to the cell membrane or degraded in the lysosome. Recycling can help the synapses recover from weakness; otherwise, it is more likely that there will be permanent damage to the receptors. Therefore, the trafficking of AMPAR should be considered a closed-loop system rather than a one-way route.

3. AMPA Receptors Trafficking in Long-Term Potentiation and Long-Term Depression

Long-term potentiation is the prolonged strengthening of synapses after some time, and to achieve it, the number of AMPA receptors on the postsynaptic membrane increases by means of activity-dependent recruitment and stabilization

[10]. NMDAR-mediated calcium influx in the CA1 neurons of the hippocampus activates CaMKII, and this activity will increase the number of AMPA receptors. CaMKII can bind to the NMDAR subunit GluN2B, move it to the postsynaptic density and start local signaling. As a result of the above cascade, there is phosphorylation of GluA1, receptor insertion and synaptic stabilization [11]. The first stage of LTP is a rapid change in receptor trafficking and conductance; the latter is caused by new protein synthesis and alters genes, structures, etc.

GluA1 has been involved in the induction of LTP. Through experiments, it has been discovered that GluA1-containing AMPA receptors can be added to the strengthened synapses after activity and that phosphorylation at the C-terminus of GluA1 promotes plasticity in some cases [12]. LTP mechanisms are not the same everywhere. Different synapses, stimulation patterns and developmental stages may have somewhat different trafficking routes. Some studies have shown that the increase in synaptic strength may be due to the addition of many types of receptors, not just an increase in one type. Therefore, it can be concluded with more certainty that AMPAR trafficking is required for many forms of LTP, but the specific molecular path differs in different situations.

AMPAR synaptic trapping is also a form of receptor delivery. Only an increase in the number of surface receptors will increase synaptic transmission if the number of receptors on the postsynaptic membrane is still small. PSD-95 and TARPs are associated with the reduction of synaptic transmission [6]. Phosphorylation of Stargazin reduces its affinity for negatively charged membrane lipids, and thus it cannot be associated with PSD-95 at the synapse. Therefore, in general, the regulation of LTP is a coordinated change in receptor exocytosis, lateral movement and anchoring, channel properties, etc.

LTD is usually a reduction in postsynaptic AMPA receptors [3]. NMDAR-dependent LTD is the result of an increase in the amount and duration of calcium entry, which then activates phosphatases such as calcineurin and PP1 to dephosphorylate AMPARs. Dephosphorylated receptors are more likely to be endocytosed from the synapse. PICK1 is needed for GluA2-dependent endocytosis, and GRIP can change the state of GluA2-containing receptors in different circumstances. METABOTE(R)LTD can alter AMPA receptor trafficking, and sometimes the reason is local protein synthesis or other signal pathways [13].

AMPAR endocytosis in LTD is related to computation. If LTP were the only way to work, the network would be saturated and have a reduced capacity for information. LTD can weaken the strength of some synapses, reverse previous potentiation, develop in an organized way, and improve behavioral flexibility. It is no longer about loss; rather, it has become an adjustment. By deleting or moving AMPARs, neurons can change the weight of some synaptic inputs and still have the ability to learn in the future.

The relationship of LTP and LTD is sometimes referred to as bidirectional regulation of synaptic AMPAR content [12]. As shown in **Figure 1**, strong calcium-dependent signaling can activate the phosphorylation of CaMKII, PKA and PKC

kinases; it increases the insertion and synaptic retention of AMPA receptors, and at the same time, LDI-related signaling enhances the activity of phosphatases to dephosphorylate AMPA receptors, promote their internalization by PICK1, and be either recycled or degraded. Typically, potentiation is an increase in the number, conductance or anchoring of synaptic AMPA receptors, and depression is usually due to a reduction in the number of synaptic AMPA receptors due to internalization or destabilization. However, it is not an all-or-nothing choice. Synapses are also homeostatic and plastic; there is unsilencing of silent synapses and local structural changes in dendritic spines. AMPAR trafficking also participates in the above processes and can modify synaptic strength at different time scales.

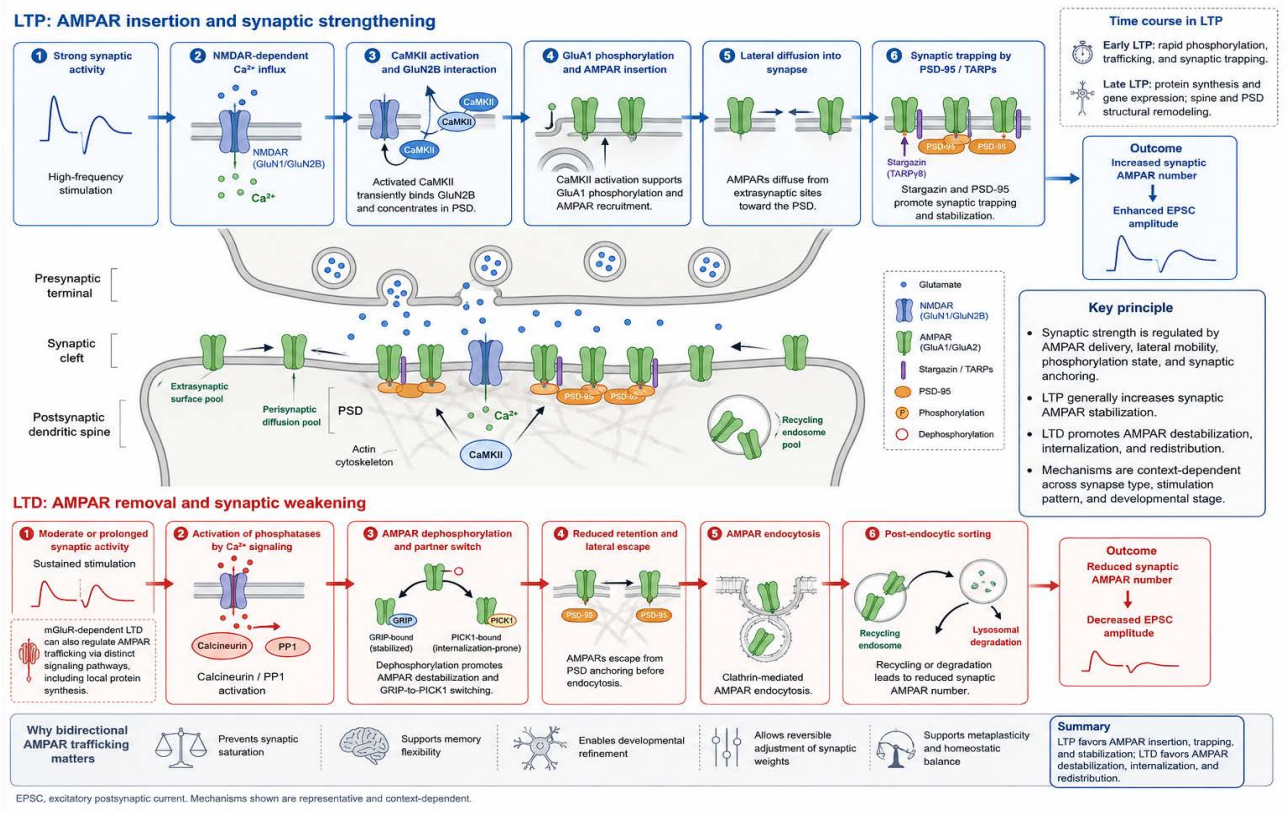

Figure 1. Molecular Model of Bidirectional AMPAR Trafficking in LTP and LTD.

4. AMPAR Trafficking, Learning, Memory and Cognitive Function

Learning and memory require changes in neural circuits that are stable enough to influence future behavior but flexible enough to update when conditions change [2]. AMPAR trafficking is another way of this balancing. Through the formation of some patterns in neural activity, active synapses are strengthened via LTP-like mechanisms; thus, more AMPA receptors can conduct current more readily, increasing the probability that the postsynaptic neuron will fire after receiving this particular input. Extinction is a reduction in the density of LTR/DTPs and weakens the earlier association.

Research on the hippocampus memory has also connected with AMPAR trafficking and Cognition. The hippocampus is essential for some kinds of episodic and spatial memory, and LTP in the hippocampus has been used to study experience-dependent synaptic strengthening [2]. Disruption of AMPA receptor trafficking, GluA1 phosphorylation and postsynaptic scaffolding can affect learning in animal models, and at the same time, the behavioral results are different in various tasks and compensatory mechanisms occur. Based on the above results, receptor trafficking may be involved in memory encoding and consolidation, and it has also been determined that memory is not a single molecular phenomenon.

Cognitive flexibility may require the controlled weakening or remodeling of synapses [3]. Internalization of LTD and AMPAR have been linked to reversal learning, fear extinction and adaptation to changes in environmental contingencies. In terms of psychology, plasticity is the ability of organisms to modify their predictions and behavior based on new information. If the strengthening of synapses is too long-lasting, the behavior may become fixed; if the weakening of synapses is too severe, the stability of memory will be affected. AMPAR trafficking is thus one of the stability-plasticity problems that have appeared in neuroscience, cognitive science and artificial intelligence.

The anterior part of the brain is a working memory and decision-making center; it also regulates impulse and planning. AMPAR trafficking in the prefrontal cortex can interfere with memory and learning. Stress hormones, neuromodulators and development changes can change glutamatergic signaling in this area and thus affect cognitive control. Molecularly speaking, it is complicated, but the effect of receptor trafficking on synaptic strength and circuit function has been demonstrated in some studies.

Memory is also influenced by sleep, metabolism, inflammation, aging, the environment, etc. Due to the above reasons, Synaptic plasticity and receptor trafficking will change as a result of alterations in the intracellular signaling pathway. Sleep is related to synaptic homeostasis, and with age, there have been changes in glutamatergic signaling and a reduction in some systems' plasticity [14]. It would be too strong a claim that AMPAR trafficking alone accounts for the above. AMPAR regulation is a possible molecular path that changes in general physiology can influence cognition.

5. Dysregulation of AMPAR Trafficking in Neurological and Psychiatric Disorders

As AMPAR trafficking regulates the strength of excitatory synapses, abnormal trafficking is associated with many neurological and psychiatric diseases [8]. In the presence of diseases, receptor trafficking may be disrupted due to amyloid pathology, tau dysfunction, stress hormones, inflammatory signals, genetic factors, inappropriate drug use, etc. Therefore, the synapses may be weakened; there will be excitotoxicity and learning loss; or the circuit will be altered abnormally.

For example, in Alzheimer's Disease, synapse loss correlates strongly with

cognitive decline, and soluble amyloid-beta oligomers have been reported to impair synaptic plasticity and promote synaptic dysfunction [15] [16]. Amyloid-beta may interfere with the transport of glutamate receptors and reduce the function of synaptic AMPARs, but it does so in different ways. Too many internalizations of receptors or insufficient stabilization of synaptic AMPA receptors can lead to early cognitive impairment before serious neuronal damage. Pathology of tau can also affect postsynaptic signaling and receptor localization. Although the mechanism is not yet known, synaptic receptor trafficking is still one of the early problems in understanding the disease.

Depression and stress-related disorders involve changes in glutamatergic signaling, synaptic connectivity, and plasticity [7]. Chronic stress can decrease the plasticity of the hippocampus and prefrontal cortex, modify dendritic architecture, alter receptor density, etc. Ketamine is a fast-acting antidepressant that has drawn considerable research attention, and it has been discovered that to manifest the behavior change effect in some models, there needs to be an enhancement of AMPA receptor-mediated synaptic plasticity. It is not to be expected that depression is merely a problem of AMPAR trafficking. Changes in the trafficking of receptors are probably one of many changes in stress biology, neuromodulation, inflammation and network function.

Addiction is another case that AMPAR trafficking is associated with maladaptive learning. Prolonged use of drugs will change the amount and strength of AMPA receptors in the reward pathway nucleus accumbens and ventral tegmental area. Some drugs can increase the number of calcium-permeable AMPA receptors, and this may be associated with the beginning of craving and changes in cue response. The above changes can be considered pathological plasticity; that is to say, the learning mechanism usually associated with adaptation is employed by drug-associated cues and reinforcement history.

Disorders of neurodevelopment are associated with imbalances in excitation and inhibition and changes in the function of synaptic proteins in autism spectrum disorder, intellectual disability syndromes, etc. [17]. Damage to scaffolding proteins and alterations in the regulation of translation and receptor signaling can all change the movement of AMPA receptors and synaptic development. There is an increase in metabotropic glutamate receptor-dependent LTD in some models of Fragile X syndrome. The link between the animal model and human clinical phenotypes is still relatively weak; however, receptor trafficking may be one of the reasons for different circuits in different genes.

The clinical relevance of AMPAR trafficking should be stated carefully. Many of the results are from animal models, cultured neurons or acute slices, and the diseased state has many interconnected factors. Changes in the level of AMPA receptors around the synapses of neurons in all parts of the body are also detrimental. In the future, the direction of treatment will be more specific according to different receptor subtypes, signal transduction pathways, cell populations or different time periods; it will no longer be a general AMPAR trafficking approach.

6. Bibliometric Analysis of Research on AMPAR Trafficking and Synaptic Plasticity

Bibliometric analysis can be used to show the development trend of research in the field of biochemical reviews. In this review, the bibliometric component was designed as a preliminary descriptive analysis of AMPAR trafficking and synaptic plasticity research rather than as a complete citation-network study. The purpose was to support the biochemical review by identifying annual publication trends and frequently indexed research terms related to AMPAR trafficking, LTP/LTD, receptor phosphorylation, synaptic localization, and learning-related plasticity.

6.1. Bibliometric Data Source and Search Strategy

The dataset used for **Figure 2** and **Figure 3** was retrieved from PubMed through the National Center for Biotechnology Information (NCBI) E-utilities interface. The search was last updated on July 2, 2026. No lower publication-year filter was imposed during retrieval; the final downloaded records covered the publication years 2000-2026. The PubMed search was performed in the Title/Abstract field using the following query: ((“AMPA receptor trafficking” OR “AMPAR trafficking” OR (“AMPA receptor” AND “synaptic plasticity”) OR “AMPA receptor internalization” OR “GluA1 phosphorylation” OR (“GluA2” AND “PICK1”) OR (“stargazin” AND “AMPA receptor”)) AND (“synaptic plasticity” OR “LTP” OR “LTD” OR “memory”)). The exported metadata included PMID, author names, article title, journal/source title, publication year, abstract, available author keywords, PubMed MeSH/indexing terms, DOI, and PubMed URL.

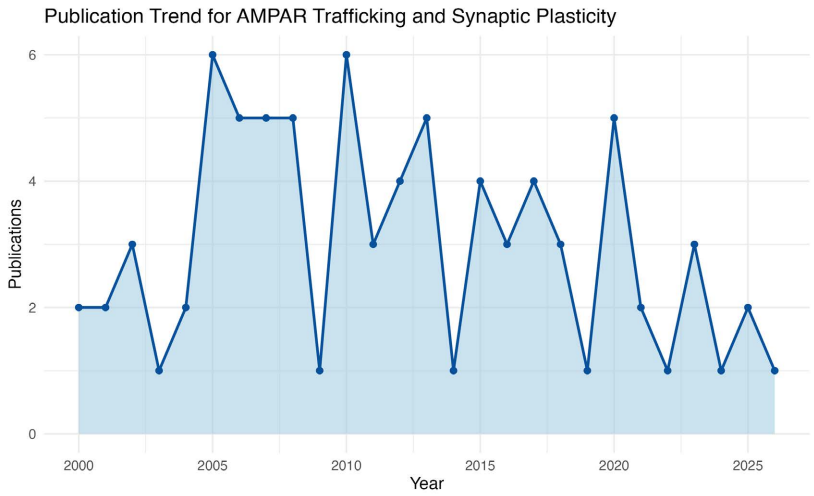

Figure 2. Preliminary annual publication trend based on the PubMed-derived AMPAR trafficking dataset. Data source: PubMed records retrieved through NCBI E-utilities on July 2, 2026, using Title/Abstract search terms for AMPA receptor trafficking, AMPAR trafficking, AMPAR internalization, GluA1 phosphorylation, GluA2/PICK1, stargazin, synaptic plasticity, LTP, LTD, and memory. The final screened dataset contained 81 records published between 2000 and 2026. Annual counts were calculated from the publication year field (PY) in R; the figure should be interpreted as a preliminary PubMed-based trend rather than a full Web of Science/Scopus bibliometric result.

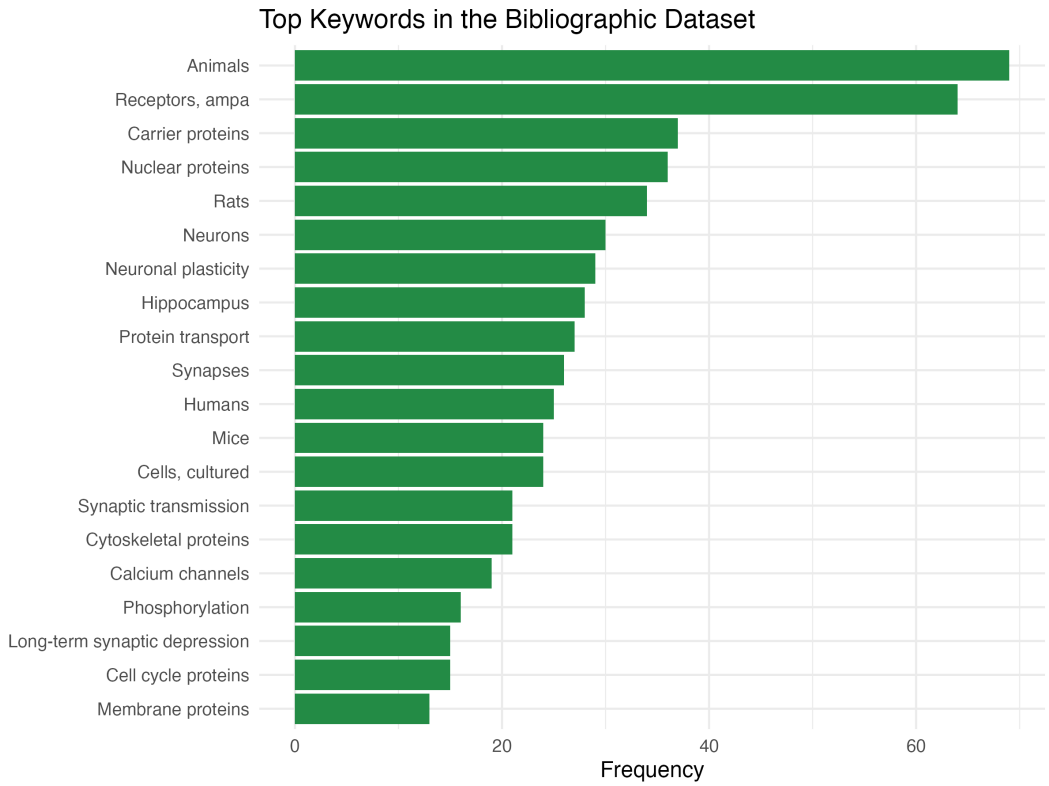

Figure 3. Most frequent indexed terms in the preliminary PubMed-derived AMPAR trafficking dataset. The analysis used the same 81 PubMed records as **Figure 2**. Author keywords, when available, and PubMed MeSH/indexing terms were extracted from the metadata, split by semicolon delimiters, normalized to lower case, and counted in R. The figure reports descriptive keyword frequency only; it does not represent a full co-citation, collaboration, or thematic-evolution analysis.

6.2. Screening and Eligibility Criteria

Records were included when their title, abstract, or indexing terms indicated direct relevance to AMPA receptor trafficking, AMPAR auxiliary proteins, receptor insertion/internalization, LTP, LTD, synaptic plasticity, or memory-related glutamatergic signaling; and were excluded if they were not relevant to AMPAR biology or synaptic plasticity after metadata screening, lacked a usable publication year for trend analysis, or represented duplicate entries. 81 PubMed records was used for the preliminary analysis as the final dataset. Because the dataset was based on PubMed rather than Web of Science or Scopus, citation counts, cited-reference networks, institutional collaboration networks, and co-citation maps were not interpreted as definitive results.

6.3. Data Processing and Analysis

The PubMed records were converted into a structured CSV file and analyzed in R. Annual publication trends were calculated by grouping records by the publication year field (PY). Keyword frequency analysis used available author keywords and PubMed MeSH/indexing terms, which were split by semicolon delimiters, converted to lower case, trimmed for whitespace, and counted across records [18].

The resulting processed tables were used to generate **Figure 2** and **Figure 3** with ggplot2. Therefore, these figures should be interpreted as descriptive maps of a preliminary PubMed dataset rather than as a comprehensive bibliometric analysis of the entire field.

If a more complete science-mapping study is conducted in a future version of this review, the PubMed search should be supplemented with Web of Science and/or Scopus exports using full records and cited references. Those databases would permit more robust analysis of citation networks, co-citation clusters, bibliographic coupling, author collaboration networks, country-level collaboration, and thematic evolution over time.

PubMed was used as the sole data source for the present bibliometric analysis since the bibliometric part was designed as a preliminary exploratory analysis rather than a full citation-network study. PubMed was selected due to its high-quality biomedical indexing, stable article identifiers, MeSH terms, abstracts, and direct relevance to molecular neuroscience and biochemistry.

7. Interdisciplinary Implications

The interdisciplinary significance of AMPAR trafficking roots in its ability to connect molecular mechanisms of synaptic change with broader questions about adaptation, cognition, and intelligent systems. This makes AMPAR trafficking relevant not only to neuroscience and biochemistry, but also to fields that study different levels of learning and adaptive control. The model in **Figure 4** shows the intersection of AMPAR trafficking from biochemical regulation, learning and memory, cognitive health, neuroAI and neuroengineering.

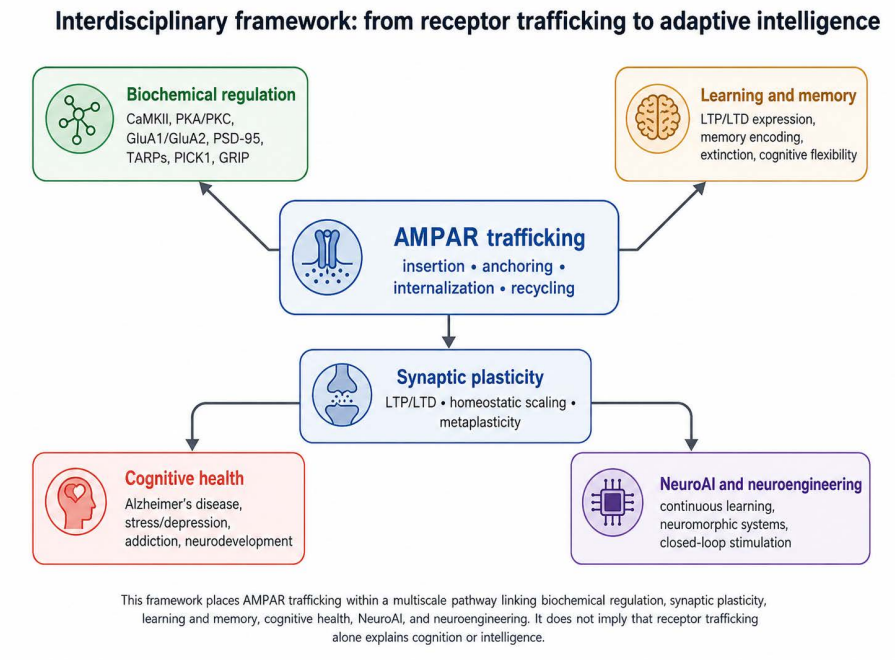

Figure 4. Interdisciplinary Framework Linking AMPAR Trafficking and Adaptive Intelligence.

7.1. NeuroAI

NeuroAI hopes that neuroscience will provide us with some ideas for building artificial intelligence that is more adaptive, efficient and general [19]. Synaptic plasticity is one of the more obvious links between biology and artificial intelligence because both are changes in connection strength. Biological plasticity is more varied than the scalar weight updates of many artificial neural networks. AMPAR trafficking shows that the strength of synapses is controlled by many interrelated factors, including the addition and subtraction of receptors, phosphorylation, movement in the membrane, local scaffolding, etc.

The atoms are more numerous and have various kinds of rules. The artificial system can separate the rapid fluctuation of weight from the slow consolidation and application of activity-dependent gating, and it also has some characteristics that are similar to receptor recycling and synaptic tagging [14]. The thresholds for LTP and LTD are the same as for adaptive learning rates and bidirectional update rules. The analogy should not be too strong; AMPARs are biological molecules and not software variables. Receptor trafficking can offer some ideas for regulating the stability and plasticity of AI to achieve continuous learning without forgetting.

7.2. Neuroengineering

Neuroengineering is to stimulate, repair or enhance the function of the nervous system [20]. AMPAR trafficking is one of the stimulation protocols for neural interfaces and may induce synaptic plasticity. All of the above are related to the ability of neural circuits to adjust directly or indirectly. To know why some stimulation patterns, cause long-term changes and others do not, we need to learn about receptor trafficking.

Neuromorphic engineering is the construction of hardware that mimics the way the brain works. A memristor is a device that changes the amount of current based on bias. AMPAR trafficking is a biological model of synapses; it is not only a tunable resistor but also an organized system with insertions, deletions, saturations, decays and memory effects [8]. Neuromorphic devices for traffic are based on this idea, and due to limited resources or other reasons, they may only have a few conductance states and local stabilization and elimination mechanisms. The above Design will promote the practice of energy conservation.

7.3. Psychology and Cognitive Health

Psychology studies behavior, learning, memory, emotions and adaptation at a level that is often far from receptor biochemistry. At the same time, at the molecular level, psychological experiences can also be expressed in the brain. Training, stress, sleep, therapy and environmental enrichment can all affect synaptic plasticity via neuromodulation and other changes in the cell. AMPAR trafficking is probably one of the changes in brain that can alter cognition.

In terms of cognitive health, it should be stressed that interventions should maintain plasticity and not disrupt memory. Exercise, cognitive stimulation, sufficient

sleep, stress regulation and socialization are all beneficial for the health of the brain; however, their molecular mechanisms differ and cannot be summarized in terms of AMPA receptor trafficking. A general system should be able to link receptors with behavior reasonably well and not be too simple. AMPAR trafficking in psychology does not aim to replace cognitive theories, but rather to add a way for experience to be stored in our bodies to them.

8. Limitations

May mechanistic proofs of the trafficking of AMPA receptors have been obtained in animal models, cultured neurons, acute brain slices and molecular perturbation experiments [7]. These systems have provided some reasons for the problems but not the whole picture. Second, the AMPAR trafficking mechanism differs according to the brain area, development stage, cell type, type of synapse and induction protocol. General statements about LTP and LTD should be qualified. Third, the link between receptor trafficking and behavior is not direct. A change in GluA1 phosphorylation or AMPAR internalization will alter synaptic strength, but behavior is the result of many distributed networks, circuits, neuromodulation, body conditions, etc., and the environment.

The Bibliometric part is also flawed. The bibliometric analysis was based only on PubMed records and did not include Web of Science or Scopus. This choice limits the comprehensiveness of the analysis, especially for citation counts, co-citation networks, institutional collaboration patterns, country-level collaboration, and thematic evolution. Moreover, the search term determines what is included, and different areas in interdisciplinary studies may have different words. Older and more famous works have better citation statistics. There will be multiple copies of the database, different author names, and missing abstracts. More open search records and proper cleaning and organization of data will reduce these problems; in analysis, we will be more careful, but some will still exist.

Lastly, AMPAR trafficking can be inspired by artificial intelligence as a concept, but it is not to be substituted for it. The functioning of biological synapses is limited by metabolism, development, noise, embodiment and evolutionary history. The mathematics and engineering behind artificial networks are not the same. The most useful interdisciplinary work will find universal laws and keep the different characteristics of various systems.

9. Future Directions

In the future, more research will be carried out at the level of molecules to study circuits and their behavior. Newer methods of imaging, optogenetics, chemogenetics and single-molecule tracking can observe the movement of AMPA receptors under different types of learning. In conjunction with electrophysiology and behavior tests, it is hoped that the mechanism of receptor trafficking in memory encoding, consolidation, retrieval and extinction can be revealed. Cell-type specific studies will need to be conducted because the same receptor mechanism can

have different effects in excitatory neurons, inhibitory interneurons, hippocampal circuits, prefrontal networks and reward pathways.

Research on diseases should be more specific in terms of biology and feasible to treat. In the future, it will be studied how amyloid-beta, tau, inflammation and metabolic disorders affect the transport of AMPA receptors in the early stages of Alzheimer's disease. Depression and stress are general diseases of adulthood that have been occurring for a long time; at present, most research has focused on AMPA receptor-mediated signaling, synapse formation and changes in neural circuits. To know about calcium-permeable AMPA receptors and cue-induced plasticity in addiction can help us find new ways to prevent relapse [21].

Computational and engineering work should not be reduced to simple metaphors of synaptic weights. A model that has added receptor pools, trafficking speed, activation threshold, synaptic tagging and homeostasis can better describe the biological phenomenon of learning [22]. Neuromorphic systems can explore the hardware analogue of receptor insertion and deletion, and research in NeuroAI will investigate whether trafficking-inspired learning rules improve continual learning and robustness. Interdisciplinary cooperation is required because although the structure of molecules can assist in the development of algorithms, generalized algorithms cannot address all variations in life.

Due to the change in area, updates to the bibliometric analysis will also need to be carried out regularly. For the beginning of a student's research, an easily managed dataset from Web of Science or Scopus can be used to study the trend and keyword network of publications, and then compare the literature on molecular AMPARs.

10. Conclusions

AMPAR trafficking is a central molecular mechanism through which neuronal activity can produce durable changes in excitatory synaptic strength [7]. AMPAR trafficking should be enabled to promote synaptic plasticity and experience-dependent modification of the brain. Regulation of receptor insertion, endocytosis, recycling, phosphorylation and synaptic anchoring in neurons can modify the strength of different synapses by means of experience. The above are the origins of LTP and LTD, as well as learning, memory, cognitive flexibility and susceptibility to neurological and psychiatric disorders.

AMPAR trafficking provides a biologically specific link between synaptic plasticity and adaptive cognitive function. Although learning, memory, and cognitive flexibility cannot be reduced to a single receptor mechanism, changes in AMPAR localization and function help explain how activity-dependent biochemical events may influence circuit-level information processing [23].

Dysregulated AMPAR trafficking may contribute to neurological and psychiatric vulnerability. Evidence from Alzheimer's disease, depression, stress-related disorders, addiction, and neurodevelopmental conditions suggests that abnormal glutamatergic receptor regulation can disrupt synaptic stability and plasticity,

although further causal and translational research is needed.

A useful interdisciplinary framework for connecting molecular neuroscience with bibliometrics, NeuroAI, neuroengineering, and cognitive health is offered by AMPAR trafficking [19] [20]. The preliminary PubMed-based bibliometric analysis suggests that AMPAR trafficking remains an active research area, while future multi-database studies could better map its broader scientific development. Overall, AMPAR trafficking should be understood not as a complete explanation of intelligence, but as a mechanistic model of adaptive synaptic change across biological and computational contexts.

Data and Software Availability

The bibliographic records used in the first stage of bibliometrics were acquired via NCBI E-utilities from PubMed and have been stored with the project files. Analysis scripts and processed tables are in the project code and data folders for reproduction.

The bibliometric dataset used for **Figure 2** and **Figure 3** was retrieved from PubMed through NCBI E-utilities on July 2, 2026. The preliminary dataset contained 81 records published between 2000 and 2026 and included PMID, authors, title, source, publication year, abstract, keywords/indexing terms, DOI, and PubMed URL. The workflow used R for data cleaning, annual publication counts, and keyword-frequency visualization. The bibliometric package was used or documented as part of the science-mapping workflow and should be cited according to its developers' recommendations [18].

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The open-source scientific software and public biomedical databases that were used to organize the literature and conduct the initial bibliometric analysis are also mentioned here. The author used ChatGPT (OpenAI) for assistance in conceptualizing and refining schematic figure design. The scientific content, interpretation, and final responsibility for the manuscript remain with the author.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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