LOG ID	BOOK REFERENCE	RCT FILTER	CONFIDENCE TIER
SEC 2.4.1	CHAPTER 2: OPERATING SYSTEM (Narrative Layer)	**ON**	**CONSENSUS**

AUDITED CLAIM

UNIT TEST (MENTAL REHEARSAL)

SYSTEMS MODEL — AS STATED IN THE BOOK

> Because vivid mental rehearsal boots up the same core **simulation architecture** as a physical event, the new neural pathway is **pre-compiled offline**.

VALIDATION QUERY

Does vivid mental rehearsal or motor imagery induce similar neuroplastic changes and activate the same neural pathways as physical execution?

EMPIRICAL FINDING

Neuroimaging and motor control studies validate that vivid mental rehearsal activates substantially overlapping neural networks and induces genuine **use-dependent neuroplasticity**. While lacking full sensory feedback, the brain utilizes the same core simulation architecture, allowing new behavioral scripts to be effectively **cached offline**.

PRIMARY ANCHORS

→ Ruffino et al., 2019, Scientific Reports

→ Bonassi et al., 2017, Scientific Reports

ABOUT THIS RECORD

Each claim in the book is decompiled from its IT metaphor into a naked, falsifiable scientific claim, then anchored to a **primary peer-reviewed source**. Claim and anchor are queried against the Consensus academic database (200M+ papers) under a fixed protocol — top-tier **Q1/Q2 journals only**, preprints excluded, human studies only. If a hypothesis fails the audit, the build is rejected: the AI generates the syntax; the peer-reviewed grid validates the physics.

CONFIDENCE TIERS

- **CONSENSUS ◀ this log** — broadly established, highly replicated mechanics.
- **EMERGING** — plausible, actively researched; no universal consensus yet.
- **EXPERIMENTAL** — contested, extrapolated, or purely theoretical.

RCT FILTER — Controlled Studies is ON for interventions (a forced action must beat a control) and OFF for mechanisms (so foundational neuroscience isn't blocked).

Yes, **motor imagery activates overlapping motor networks** and induces **similar but usually weaker plasticity** than execution.

1. Introduction

Vivid mental rehearsal, usually studied as motor imagery, does induce neuroplastic changes and does recruit many of the same neural pathways as physical execution, but the equivalence is partial rather than complete. Across healthy participants, athletes, patients with stroke, spinal cord injury, Parkinson's disease, and other neurological conditions, motor imagery repeatedly engages supplementary motor, premotor, parietal, cerebellar, and often primary motor regions that overlap with those used during overt movement (Zhenzhen et al., 2024; Li et al., 2018; Butler & Page, 2006). Controlled physiology studies also show that imagery can shift cortical movement representations, alter corticospinal excitability, and change functional connectivity, indicating genuine use-dependent plasticity rather than mere contemplation (Ruffino et al., 2019; Yoxon & Welsh, 2019; Monany et al., 2021).

The important qualification is that imagery usually produces smaller, slower, or differently distributed effects than physical practice. Direct comparisons show that physical training tends to produce stronger gains in performance and motor-cortex excitability, while imagery relies more heavily on planning-related and frontoparietal processes and lacks the sensory feedback that normally calibrates execution (Bonassi et al., 2017; Rowe & Boe, 2024). Some studies even argue that motor imagery cannot update internal models the way overt movement does, despite broad network overlap (Rowe & Boe, 2024). Clinical and augmentation studies further suggest that imagery becomes more execution-like when paired with somatosensory input, neurofeedback, or action observation (Bonassi et al., 2017; Mihara et al., 2013; Binks et al., 2023).

Does vivid mental rehearsal or motor imagery induce similar neuroplastic changes and activate the same neural pathways as physical execution?

Requires at least 5 papers that directly answer your question. Try adjusting your query to find more papers.

FIGURE 1 Consensus on motor imagery and execution overlap

2. Methods

The search was conducted over more than 170 million research papers indexed by Consensus, spanning Semantic Scholar, PubMed, and other scholarly sources. The workflow initially identified 1,700 papers for the exact query, expanded through targeted searches on shared neural substrates, neuroplasticity, rehabilitation, expertise, null findings, and multimodal methods, then screened 240 papers after machine-learned relevance filtering. From 118 eligible unique papers, the 50 most relevant human controlled studies were included for this synthesis.

Search Strategy

2.2M Retrieved → **1.9K** Eligible → **50** Included

22 searches

1 citation graph use

All papers retrieved from 22 searches and 1 citation graph use.

Papers meeting relevance and quality criteria, after deduplication

Top papers selected to be included in the final analysis

FIGURE 2 Search and screening flow for included studies

The strategy combined direct contrast studies, rehabilitation trials, expertise work, and mechanistic neurophysiology across fMRI, EEG, MEG, TMS, and BCI.

3. Results

3.1 Key Papers

A few papers anchor the literature because they directly test whether imagery changes motor representations or reorganizes motor networks in ways comparable to execution. The strongest anchors include acute TMS plasticity studies in healthy adults, somatosensory-augmentation experiments, and clinical network-reorganization studies in stroke and spinal injury (Ruffino et al., 2019; Bonassi et al., 2017; Li et al., 2018).

Paper	Summary
(Yoxon & Welsh, 2019)	Acute imagery induces use-dependent plasticity (Ruffino et al., 2019)
(Butler & Page, 2006)	Somatosensory input makes imagery more execution-like (Bonassi et al., 2017)
(Seebacher et al., 2022)	Stroke imagery training strengthens dorsal motor pathways (Li et al., 2018)

FIGURE 3 Key anchor papers in this corpus

3.2 Shared Neural Pathways

Motor imagery and execution consistently share a broad motor network, especially supplementary motor area, premotor cortex, parietal regions, cerebellum, and frequently primary motor cortex (Ruffino et al., 2021; Zhenzhen et al., 2024; Butler & Page, 2006). In healthy controls, imagery and execution differed quantitatively more than qualitatively: imagery increased inferior parietal activity and reduced supplementary motor, cingulate, and insular activity relative to execution, while preserving a common core network (Wang et al., 2023).

In spinal cord injury and ALS, imagery can still activate execution-related regions despite severe motor disconnection. Paraplegic patients showed imagery activation in primary and non-primary motor cortices and subcortical regions, with primary motor cortex activated to a degree similar to controls during execution (Alkadhi et al., 2005). ALS patients likewise activated primary, premotor, and supplementary motor cortex during both imagery and execution, with compensatory frontoparietal increases as impairment progressed (Lulé et al., 2007).

3.3 Plasticity Compared With Physical Practice

Dimension	Motor Imagery	Physical Execution	Citations
Cortical representation shift	Present after more trials	Present earlier	(Yoxon & Welsh, 2019)
M1 excitability	Often smaller or absent	Usually larger	(Bonassi et al., 2017)
Performance gains	Reliable but smaller	Larger, faster	(Bonassi et al., 2017; Ruffino et al., 2021)
Consolidation profile	Can show offline gains	Different consolidation dynamics	(Ruffino et al., 2021)

Dimension	Motor Imagery	Physical Execution	Citations
Internal-model updating	Contested or limited	Clear aftereffects	(Rowe & Boe, 2024)

Motor imagery can induce rapid cortical plasticity, but the dose-response is less efficient than physical practice. In one direct TMS comparison, both imagery and physical thumb training shifted the direction of TMS-evoked movements, but imagery required roughly three times as many trials for detectable change (Yoxon & Welsh, 2019). Another acute study found that imagery alone deviated TMS-induced thumb movements toward the trained direction and increased agonist corticospinal excitability, but the effect returned to baseline within 30 minutes (Ruffino et al., 2019).

The similarity weakens when mechanisms require real sensory error signals. A 2024 prism-adaptation study found significant aftereffects after physical practice but not after motor imagery, arguing that imagery does not update internal models in the same way as overt movement (Rowe & Boe, 2024).

3.4 Modifiers of Equivalence

The degree of overlap depends strongly on experience, sensory context, and augmentation. When imagery is supplemented with peripheral nerve stimulation, it can resemble physical practice much more closely: combined imagery plus stimulation increased movement speed, prevented further PAS25-induced LTP-like plasticity, and retained skill the next day similarly to physical practice, whereas imagery alone had only minor effects (Bonassi et al., 2017). Neurofeedback during imagery also increases premotor activation and improves post-stroke hand recovery relative to sham feedback (Mihara et al., 2013).

Experience matters as well. Less-experienced participants show more widespread, bilateral imagery activity, whereas experts show more focused and efficient recruitment during sport-specific imagery (Kraeutner et al., 2018; Chang et al., 2010). In dancers, expertise shifts kinesthetic imagery toward stronger bilateral sensorimotor engagement and less prefrontal demand, again suggesting that imagery becomes more execution-like with practiced motor representations (Orlandi et al., 2020).

Results Timeline

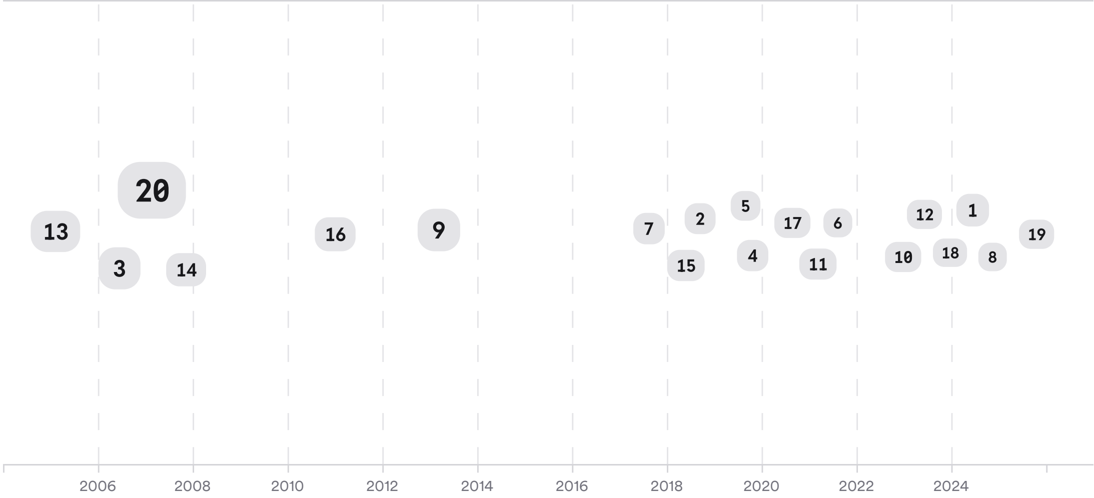

FIGURE 4 Timeline of motor imagery findings; larger markers indicate more citations

Top Contributors

Type	Name	Papers
Author	F. Lebon	[3d380e4aa1825255af33e1e75181a493][8697adcd1b895f2c92596317d12e3249] [b9b0fd492c175e5eba51fbb838cc8969][3f35d1e4130f53acb99f3032cd85102b]

Type	Name	Papers
Author	C. Papaxanthis	[3d380e4aa1825255af33e1e75181a493][9312d3578eaa5c3491ca814495c577aa][8697adcd1b895f2c92596317d12e3249][b9b0fd492c175e5eba51fbb838cc8969][3f35d1e4130f53acb99f3032cd85102b]
Author	Stephen J. Page	[8e16cb0959b250f5a6ab7cbdc7e6bba4][b3254d20a60058b1817ba832d3446a1d]
Journal	*Scientific Reports*	[dc4e22ae64c251c9961eea3b1c3b6c2f][3d380e4aa1825255af33e1e75181a493][8697adcd1b895f2c92596317d12e3249][a4fe69c46703572ea98aa6595bc94c54]
Journal	*Journal of NeuroEngineering and Rehabilitation*	[0c38d28733115d8ebfd683c879103cc2][32f458d9ee0154ca974af249ea9f0ae5][44beba86d3f853dabefa1ffa259b1a8e]
Journal	*Stroke*	[ac6df6b9134054f094793cf64a8ea1c6][8e16cb0959b250f5a6ab7cbdc7e6bba4]

FIGURE 5 Authors and journals most frequent in included papers

4. Discussion

The overall evidence supports a moderate-to-strong version of functional equivalence: motor imagery is not inert, and it does engage core motor circuits while producing measurable plasticity in cortex, corticospinal pathways, and network connectivity (Ruffino et al., 2019; Li et al., 2018; Monany et al., 2021). This conclusion is strengthened by converging methods. TMS studies show representation shifts and excitability changes, fMRI and MEG show overlapping regional recruitment and altered connectivity, and rehabilitation studies show accompanying behavioral improvement (Yoxon & Welsh, 2019; Di Rienzo et al., 2023; He et al., 2025).

But strict equivalence is too strong. Motor imagery usually recruits the same pathways with lower intensity, greater prefrontal and parietal involvement, and no actual sensory feedback, which likely explains why behavioral gains are often smaller and some mechanisms of motor adaptation fail to appear (Bonassi et al., 2017; Li et al., 2018; Rowe & Boe, 2024). That pattern also explains mixed clinical efficacy: some stroke trials show functional benefit and cortical activation changes, while others find no added benefit over control care despite a plausible neural rationale (Page et al., 2007; Ietswaart et al., 2011).

The best interpretation is that imagery and execution share a common motor simulation architecture, but physical execution adds afferent feedback, stronger corticospinal output, and richer error signals. Studies that restore some of that missing information through electrical stimulation, neurofeedback, or combined action observation tend to produce more execution-like effects (Bonassi et al., 2017; Mihara et al., 2013; Binks et al., 2023).

Claim	Evidence Strength	Reasoning	Papers
Motor imagery activates many of the same motor-related regions as execution	Strong	Replicated across imaging, patients, and healthy adults	(Zhenzhen et al., 2024; Alkadhi et al., 2005; Butler & Page, 2006)
Motor imagery induces real neuroplastic changes	Strong	TMS, connectivity, and training studies show measurable brain change	(Ruffino et al., 2019; Marins et al., 2019; Monany et al., 2021)
Plasticity from imagery is usually weaker than from execution	Strong	Direct head-to-head comparisons show smaller or slower effects	(Yoxon & Welsh, 2019; Bonassi et al., 2017; Ruffino et al., 2021)

Claim	Evidence Strength	Reasoning	Papers
Sensory augmentation makes imagery more execution-like	Moderate	Multiple intervention studies support enhanced effects with added feedback	(Bonassi et al., 2017; Mihara et al., 2013; He et al., 2025)
Motor imagery updates internal models just like execution	Weak	Direct recent evidence argues against full equivalence here	(Rowe & Boe, 2024)

FIGURE 6 Key claims and evidence from included papers

5. Conclusion

Motor imagery induces similar neuroplastic changes and activates similar neural pathways to physical execution in a broad but incomplete sense. The overlap in motor-network recruitment is robust, and the plasticity is real, but the effects are typically weaker, slower, and more dependent on task experience and augmentation than those produced by actual movement (Yoxon & Welsh, 2019; Ruffino et al., 2021; Chen et al., 2025).

Research Gaps

The largest gaps concern direct head-to-head mechanistic comparisons, long-term structural outcomes, and conditions under which imagery can or cannot substitute for overt practice.

Topic/Outcome	Motor Cortex Plasticity	Internal Model Updating	Long-Term Structure	Clinical Generalization
Healthy acute training	8	3	2	2
Stroke rehabilitation	10	1	4	10
Spinal cord injury	4	1	1	4
Expertise and sports	7	2	1	5
Augmented MI-BCI and neurofeedback	6	1	3	6

Open Research Questions

Direct substitution remains unresolved, especially for adaptation mechanisms and long-term rehabilitation dosing.

Question	Why
Under what sensory augmentation conditions can motor imagery reproduce the motor-cortex plasticity of physical practice?	Electrical stimulation, neurofeedback, and BCI improve effects, but the minimum ingredients for execution-like plasticity remain unclear.
Which aspects of motor learning can imagery support without real sensory error signals?	Recent prism-adaptation results challenge full internal-model equivalence despite strong overlap in activation and performance gains.

Question	Why
Who benefits most from motor imagery alone versus imagery combined with physical practice?	Stroke, spinal injury, athlete, and expertise studies suggest response depends on preserved networks, experience, and impairment profile.

In answer to the question: yes, vivid mental rehearsal activates substantially overlapping motor pathways and can induce comparable forms of neuroplasticity, but not to the same extent or through exactly the same mechanisms as physical execution.

References

Z., Wu, J., Cao, Z.-W., Hua, X.-Y., Zheng, M., Xing, X.-X., J., & Xu, J. (2024). Motor imagery-based brain–computer interface rehabilitation programs enhance upper extremity performance and cortical activation in stroke patients. *Journal of NeuroEngineering and Rehabilitation, 21*. https://doi.org/10.1186/s12984-024-01387-w

Alkadhi, H., Brugger, P., Boendermaker, S. H., Crelier, G., Curt, A., Hepp-Reymond, M., & Kollias, S. (2005). What disconnection tells about motor imagery: evidence from paraplegic patients.. *Cerebral cortex, 15 2*, 131-40. https://doi.org/10.1093/cercor/bhh116

Binks, J., Emerson, J., Scott, M., Wilson, C. J., Van Schaik, P., & Eaves, D. (2023). Enhancing upper-limb neurorehabilitation in chronic stroke survivors using combined action observation and motor imagery therapy. *Frontiers in Neurology, 14*. https://doi.org/10.3389/fneur.2023.1097422

Bonassi, G., Biggio, M., Bisio, A., Ruggeri, P., Bove, M., & Avanzino, L. (2017). Provision of somatosensory inputs during motor imagery enhances learning-induced plasticity in human motor cortex. *Scientific Reports, 7*. https://doi.org/10.1038/s41598-017-09597-0

Butler, A., & Page, S. J. (2006). Mental practice with motor imagery: evidence for motor recovery and cortical reorganization after stroke.. *Archives of physical medicine and rehabilitation, 87 12 Suppl 2*, S2-11. https://doi.org/10.1016/j.apmr.2006.08.326

Chang, Y., Lee, J.-J., Seo, J.-H., Song, H., Kim, Y.-T., Lee, H.-J., Kim, H. J., Lee, J., Kim, W., Woo, M., & Kim, J. G. (2010). Neural correlates of motor imagery for elite archers. *NMR in Biomedicine, 24*. https://doi.org/10.1002/nbm.1600

Chen, J., Liu, Q., Chen, G.-J., Cai, G., Jiang, J., Yang, X., Tan, C., Zhang, C., Xu, G., & Lan, Y. (2025). iTBS on RDLPFC improves performance of motor imagery: a brain-computer interface study combining EEG and fNIRS. *Journal of NeuroEngineering and Rehabilitation, 22*. https://doi.org/10.1186/s12984-025-01688-8

Di Rienzo, F., Debarnot, U., Daligault, S., Delpuech, C., Doyon, J., & Guillot, A. (2023). Brain plasticity underlying sleep-dependent motor consolidation after motor imagery.. *Cerebral cortex*. https://doi.org/10.1093/cercor/bhad379

He, J., Yuan, Z., Quan, L., Xi, H., Guo, J., Zhu, D., Chen, M., Yang, B., Cui, Z., Zhu, S., & Qiao, J. (2025). Multimodal assessment of a BCI system for stroke rehabilitation integrating motor imagery and motor attempts: a randomized controlled trial. *Journal of NeuroEngineering and Rehabilitation, 22*. https://doi.org/10.1186/s12984-025-01723-8

Ietswaart, M., Johnston, M., Dijkerman, H., Joice, S., Scott, C. L., Macwalter, R., & Hamilton, S. (2011). Mental practice with motor imagery in stroke recovery: randomized controlled trial of efficacy. *Brain, 134*, 1373 - 1386. https://doi.org/10.1093/brain/awr077

Kraeutner, S. N., McWhinney, S. R., Solomon, J. P., Dithurbide, L., & Boe, S. (2018). Experience modulates motor imagery-based brain activity. *European Journal of Neuroscience, 47*. https://doi.org/10.1111/ejn.13900

Li, F., Zhang, T., Li, B.-J., Zhang, W., Zhao, J., & Song, L. (2018). Motor imagery training induces changes in brain neural networks in stroke patients. *Neural Regeneration Research, 13*, 1771 - 1781. https://doi.org/10.4103/1673-5374.238616

Lulé, D., Diekmann, V., Kassubek, J., Kurt, A., Birbaumer, N., Ludolph, A., & Kraft, E. (2007). Cortical Plasticity in Amyotrophic Lateral Sclerosis: Motor Imagery and Function. *Neurorehabilitation and Neural Repair, 21*, 518 - 526. https://doi.org/10.1177/1545968307300698

Marins, T. F., Rodrigues, È., Bortolini, T., Melo, B., Moll, J., & Tovar-Moll, F. (2019). Structural and functional connectivity changes in response to short-term neurofeedback training with motor imagery. *NeuroImage, 194*, 283-290. https://doi.org/10.1016/j.neuroimage.2019.03.027

Mihara, M., Hattori, N., Hatakenaka, M., Yagura, H., Kawano, T., Hino, T., & Miyai, I. (2013). Near-infrared Spectroscopy–mediated Neurofeedback Enhances Efficacy of Motor Imagery–based Training in Poststroke Victims: A Pilot Study. *Stroke, 44*, 1091–1098. https://doi.org/10.1161/strokeaha.111.674507

Monany, D. R., Lebon, F., Dupont, W., & Papaxanthis, C. (2021). Mental practice modulates functional connectivity between the cerebellum and the primary motor cortex. *iScience, 25*. https://doi.org/10.1016/j.isci.2022.104397

Orlandi, A., Arno, E., & Proverbio, A. (2020). The Effect of Expertise on Kinesthetic Motor Imagery of Complex Actions. *Brain Topography, 33*, 238 - 254. https://doi.org/10.1007/s10548-020-00760-x

Page, S. J., Levine, P., & Leonard, A. (2007). Mental Practice in Chronic Stroke: Results of a Randomized, Placebo-Controlled Trial. *Stroke, 38*, 1293-1297. https://doi.org/10.1161/01.str.0000260205.67348.2b

Rowe, J. M., & Boe, S. G. (2024). Unlike overt movement, motor imagery cannot update internal models.. *Brain and cognition, 181*, 106219. https://doi.org/10.1016/j.bandc.2024.106219

Ruffino, C., Gaveau, J., Papaxanthis, C., & Lebon, F. (2019). An acute session of motor imagery training induces use-dependent plasticity. *Scientific Reports, 9*. https://doi.org/10.1038/s41598-019-56628-z

Ruffino, C., Truong, C., Dupont, W., Bouguila, F., Michel, C., Lebon, F., & Papaxanthis, C. (2021). Acquisition and consolidation processes following motor imagery practice. *Scientific Reports, 11*. https://doi.org/10.1038/s41598-021-81994-y

Seebacher, B., Helmlinger, B., Pinter, D., Ehling, R., Hegen, H., Ropele, S., Reishofer, G., Enzinger, C., Brenneis, C., & Deisenhammer, F. (2022). Effects of actual and imagined music-cued gait training on motor functioning and brain activity in people with multiple sclerosis: protocol of a randomised parallel multicentre trial. *BMJ Open, 12*. https://doi.org/10.1136/bmjopen-2021-056666

Wang, L., Zheng, W., Liang, T., Yang, Y., Yang, B., Chen, X., Chen, Q., Li, X. J., Lu, J., Li, B. W., & Chen, N. (2023). Brain Activation Evoked by Motor Imagery in Pediatric Patients with Complete Spinal Cord Injury. *American Journal of Neuroradiology, 44*, 611 - 617. https://doi.org/10.3174/ajnr.a7847

Yoxon, E., & Welsh, T. (2019). Rapid motor cortical plasticity can be induced by motor imagery training.. *Neuropsychologia*, 107206. https://doi.org/10.1016/j.neuropsychologia.2019.107206