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Imagery Training in REM Sleep and Lucid Dreaming and the Optimisation of Motor Memory Consolidation in Athletes: A Narrative Review

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Abstract

Background: Motor learning in competitive sport relies not only on physical practice but also on the offline reorganisation of memory traces during sleep. Waking motor imagery is a recognised ergogenic adjunct, while recent work suggests that mental rehearsal may be extended into the sleeping brain through lucid dreaming, a state in which the dreamer becomes aware of dreaming while remaining physiologically asleep.
Aim: To synthesise neurophysiological, behavioural and applied evidence on motor imagery, sleep-dependent memory consolidation and lucid dream practice, and to consider its potential as a complementary modality in athletic training and rehabilitation.
Material and methods: A narrative search of peer-reviewed publications was conducted in PubMed, Scopus, Web of Science and Google Scholar through 2024. Empirical and theoretical works on motor imagery, sleep-dependent consolidation, lucid dreaming neurobiology and lucid dream practice in athletic contexts were retained and synthesised.
Results: Motor imagery seems to engage cortical and subcortical networks largely overlapping with those recruited during overt action, whereas slow-wave sleep and REM may support procedural memory through hippocampal–neocortical dialogue and neural replay. Lucid REM sleep has been linked with partial reactivation of prefrontal regions and with cardiovascular,

ocular and electromyographic correlates of dreamed movement. Preliminary studies suggest that lucid dream practice may improve subsequent waking performance comparably to waking mental practice.
Conclusions: Lucid dream practice may represent a complementary, low-physical-load modality with potential applications in rehabilitation, tapering and pre-competition stress management. Low lucid dream frequency, variable induction reliability and few controlled trials in elite samples call for cautious implementation.

Keywords: lucid dreaming; motor imagery; sleep; memory consolidation; REM sleep; sport performance

1. Introduction

1.1. The Role of Mental Training in Modern Elite Sport

Competitive sport at the elite level has gradually moved away from a purely biomechanical and conditioning-oriented paradigm towards an integrative model in which physical, technical, tactical and psychological preparation are treated as interdependent components of long-term athletic development. Several authors have argued that, in disciplines requiring complex perceptual–motor coordination, the cognitive and affective dimensions of performance may be as decisive as muscular strength, aerobic capacity or anaerobic power [1]. Within this framework, mental training has gradually evolved from a marginal supplement, used occasionally by individual coaches, into a relatively well-codified area of applied sport psychology, with its own intervention protocols, validated measurement tools and theoretical models [1, 2]. The systematic review by Slimani and colleagues, focused specifically on soccer players, concluded that cognitive strategies — and imagery in particular — appear to support both motor and positive psychological skill development, especially when several techniques (for instance, imagery, self-talk and relaxation) are combined within a single intervention package [1].

Among the techniques that comprise the broader category of mental training, visualisation and motor imagery occupy a central position. Visualisation, often used interchangeably with the term guided imagery, has been described as the cognitive recreation or generation of a perceptual experience without any matching external stimulus, ideally engaging multiple sensory modalities and being framed by emotional and contextual cues that resemble those of the actual competitive setting [2]. Predoiu and colleagues underlined that, when performed in a controlled and systematic manner, visualisation may sharpen attentional focus, may attenuate competitive anxiety, may support the regulation of pre-start arousal and may speed up the acquisition of new technical–tactical patterns [2]. The same authors note that an internal (first-person) imagery perspective tends to be favoured by practitioners and seems to map more closely onto the proprioceptive experience of actual performance, although external (third-person) imagery may retain a useful role in form-based skills and in early stages of technical learning [2].

The construct that anchors much of this work in contemporary cognitive neuroscience is motor imagery, conventionally defined as a dynamic mental state in which the representation of a given motor act is rehearsed in working memory without overt motor output [3]. As Moran and colleagues have pointed out, the term itself has been used with some terminological inconsistency across disciplines — for instance, as a synonym of "movement imagery", "kinaesthetic imagery" or "internal visual imagery" — yet a common conceptual core has been preserved: the deliberate, conscious simulation of action in the absence of muscular execution, often associated with subjective sensations resembling those experienced during the corresponding overt task [3]. The bridge between cognitive neuroscience and sport psychology has been built largely around the so-called functional equivalence hypothesis, which posits that imagined and executed actions share, at least partially, neural substrates and representational formats, including regions of the premotor cortex, the supplementary motor area, the basal ganglia, the parietal cortex and the cerebellum [3, 4].

The neurophysiological plausibility of motor imagery has been further reinforced by work on action observation and on the combined paradigm in which observation and imagery are deployed concurrently. Zhang and Luo, in a recent review, summarised converging evidence indicating that motor imagery activates brain regions associated with motor planning and execution to a degree that is weaker but topographically similar to that elicited by overt movement, and that the simultaneous use of action observation and motor imagery (the so-called AO+MI paradigm) may recruit an even broader network and produce additional benefits for motor learning and rehabilitation [4]. From the perspective of an applied sport psychologist, this convergence between two distinct lines of evidence — chronometric and behavioural studies on the one hand, neuroimaging on the other — provides a relatively robust rationale for embedding imagery-based work in everyday training routines, particularly in technical sports in which precision, timing and the anticipation of opponents' actions are decisive [1, 3, 4].

Several testimonies from high-performance contexts, often cited in narrative reviews, illustrate the practical visibility of these techniques. Predoiu and colleagues, for example, recall the case of an internationally renowned swimmer, who reportedly used systematic visualisation to rehearse every conceivable race scenario — including those involving equipment failure — so that his nervous system could draw, in real time, from a "database" of prepared responses [2]. While such accounts are anecdotal and therefore should be treated with caution, they are consistent with empirical findings indicating that imagery may contribute to performance enhancement, motivational regulation, pain tolerance and confidence, and that its efficacy is moderated by imagery ability, attentional focus, perspective and the structure of the practice schedule [1, 2, 3]. Importantly, recent contributions in this area have begun to consider whether the well-known benefits of imagery during wakefulness might be extended into the sleeping brain, a hypothesis that, although still partly speculative, motivates much of the work synthesised in the present narrative review [5, 6, 7].

1.2. The Limitations of Classical Physical Training and Sleep as an Ergogenic Strategy

Despite the substantial gains generated by progressive overload and periodised physical training, modern elite sport appears to be approaching what some authors describe as a "bottleneck" of classical conditioning. The consensus statement on recovery and performance issued by an international panel of sport scientists explicitly underlines that the balance between training and competition load and recovery is essential for sustained high-level performance, and that an imbalance in this equation may trigger a cascade of deleterious states ranging from underrecovery, through non-functional overreaching, up to overtraining syndrome [8]. The same authors stress that increasing training volume in the hope of producing further gains may, paradoxically, undermine adaptation when systematic recovery is not concurrently programmed, since the resulting accumulation of fatigue may dampen the very processes responsible for performance improvement [8]. This observation has been echoed by reviews concerned specifically with injury epidemiology and recovery, which converge on the notion that the marginal gains attainable through purely physical means tend to diminish as athletes approach the upper limits of their physiological capacity [8, 9].

In parallel, a robust body of evidence has linked insufficient or fragmented sleep with a measurable increase in injury risk among athletic populations. The systematic review by Bartkowska and colleagues, focused on sleep parameters and sports injuries, concluded that strong evidence connects short and poor-quality sleep with a substantially higher likelihood of musculoskeletal injury, and that the underlying mechanisms appear to involve impaired cognitive functioning, slowed reaction time, weakened neuromuscular control, increased inflammation and impaired tissue regeneration [9]. The notion of sleep as an "ergogenic supplement" — a performance-enhancing intervention that does not require pharmacological aids — has gradually gained traction in the sport sciences, and is supported by experimental work in which sleep extension in collegiate basketball players translated into improved sport-specific performance and increased daytime alertness [9]. A complementary systematic review concerning sleep and athletic performance reached a similar conclusion, emphasising that adequate sleep duration and quality are associated with improved reaction time, mood, cognitive function and physical readiness, while sleep restriction has been related to detrimental effects on aerobic and anaerobic performance, perceived exertion and the consistency of skill execution [10].

The disparity between sleep needs and actual sleep patterns in elite athletes has been documented in several studies. Kölling and colleagues report that, while the National Sleep Foundation recommends 7–9 hours of sleep for young adults, sleep durations in athletic populations are frequently below seven hours, with values around 6.8 hours in mixed cohorts of elite individual and team-sport competitors, and even shorter durations in individual sports such as cycling, race-walking and swimming [11]. Approximately half of the elite or highly trained team-sport athletes assessed in questionnaire-based studies were classified as poor sleepers, and a clinically significant proportion presented daytime sleepiness or signs of obstructive sleep apnoea [11]. The same authors highlight several contextual factors that may help to explain these patterns, including the scheduling of training and competition (late-night games, early-morning practices, intercontinental travel and jet-lag), pre-competitive anxiety and the increasing use of electronic devices before bedtime [11]. A Polish narrative review by Frydrych-Szymonik and colleagues converges on these conclusions, arguing that sleep disorders in athletes often stem from insufficient knowledge of sleep hygiene and that the introduction of properly scheduled regenerative naps and lifestyle interventions may meaningfully support recovery and performance [12].

Beyond its restorative role at the systemic and metabolic level, sleep is now recognised as an active state in which memory traces acquired during wakefulness are processed, stabilised and reorganised. Fabian and colleagues, in a wide-ranging narrative review, recall that sleep is not a passive interruption of cognition but rather a complex physiological process during which the glymphatic system is markedly upregulated, neuroendocrine functions are recalibrated and memory consolidation processes unfold [13]. According to the standard two-stage memory model, freshly encoded representations stored in the hippocampus are gradually transferred to neocortical networks, with sleep acting as the privileged time window during which the relevant neural reactivations may take place [13, 14, 15]. The seminal experimental study by Walker and colleagues, using a sequential finger-tapping task, showed that a night of sleep was associated with an approximately 20% improvement in motor speed without loss of accuracy, whereas an equivalent waking interval did not produce comparable gains [14]. Furthermore, the magnitude of overnight improvement correlated significantly with the proportion of stage 2 non-rapid eye movement (NREM) sleep, particularly in the last quarter of the night, pointing to a sleep-stage-dependent component of motor memory consolidation [14].

The mechanistic foundations of these behavioural observations have been articulated in detail by Diekelmann and Born, who proposed that slow-wave sleep and rapid eye movement (REM) sleep support, respectively, system consolidation and synaptic consolidation, through specific patterns of neuromodulatory activity and electric field potential oscillations [15]. During slow-wave sleep, slow oscillations, sleep spindles and hippocampal sharp-wave ripples appear to coordinate the reactivation and redistribution of hippocampus-dependent memories towards neocortical sites, while during REM sleep, local increases in plasticity-related gene expression — in a context of high cholinergic and theta activity — may favour the subsequent synaptic consolidation of cortical memories [15]. This framework provides a theoretical scaffold for understanding why sleep, in the context of elite sport, may not be reducible to a "passive" recovery strategy comparable to massage or hydrotherapy, but rather may constitute an active, ergogenic process directly relevant to motor learning and skill acquisition [8, 11, 14, 15].

A particularly informative line of work, embedded in this broader literature, concerns the interplay between motor imagery, physical practice and sleep. Debarnot and colleagues demonstrated that participants who imagined performing a sequential finger task showed offline performance gains after a night of sleep — comparable to those observed after actual physical practice — while a control group trained and retested across the daytime did not exhibit such delayed improvements [16]. These findings imply that the well-known benefits of mental practice may be at least partly mediated by sleep-dependent consolidation processes, which raises the question of whether one might "extend" mental rehearsal beyond the boundaries of wakefulness and into the dreaming brain itself [5, 16]. It is here that lucid dreaming, a state in which the sleeper becomes aware of dreaming and may, to some extent, exert volitional control over dream content, enters the discussion as a potentially fruitful but still under-explored modality [5, 6, 7, 17].

The broader public-health context strengthens the case for treating sleep as a non-trivial determinant of performance and well-being. As Czechowicz and colleagues observe in a recent narrative review, physical activity and sleep are entangled in a bidirectional relationship in which exercise may improve sleep quality while adequate sleep may, in turn, support both mood and the capacity to engage in regular physical activity [18]. Within elite sport, this interaction acquires an additional dimension: sleep deprivation and sleep fragmentation may not only undermine recovery from a single training session but may also blunt the cumulative adaptations sought across an entire macrocycle, with potential consequences for both performance trajectories and injury risk [8, 9, 10, 11]. Taken together, these observations help to frame the search for novel methods of training optimisation as a logical response to the diminishing returns of purely physical interventions, and to position the sleeping brain as a plausible — albeit not yet fully characterised — target for such methods [5, 8, 13, 15, 17].

1.3. Aims and Research Questions

The intersection of two relatively well-established bodies of evidence — on the one hand, the literature on motor imagery and its benefits for skill acquisition; on the other, the literature on sleep-dependent consolidation of procedural memory — naturally invites a third, more speculative question: whether deliberate motor rehearsal can be performed during sleep itself, particularly during REM sleep, and whether such "sleep-bound rehearsal" might confer measurable advantages on subsequent waking performance [5, 6, 7]. Lucid dreaming, in which the dreamer becomes aware of dreaming while remaining physiologically asleep and may, in some cases, intentionally direct dream content, constitutes the natural candidate for a state in which such rehearsal could plausibly take place [17]. Preliminary empirical work suggests that motor practice performed within lucid dreams (commonly referred to as lucid dream practice, LDP) may improve subsequent waking performance to a degree that is comparable, in some studies, with that of classical mental practice in wakefulness [5, 6, 7].

The general aim of the present narrative review is to integrate, in a critical and theoretically informed manner, the available neurophysiological, behavioural and applied evidence regarding the role of motor imagery in wakefulness, the contribution of sleep architecture to procedural memory consolidation and the use of lucid dream practice as an emerging modality in athletic training and rehabilitation. More specifically, the review seeks to articulate the chain of mechanisms — from the cortical activation associated with imagined movement, through the offline reorganisation of memory traces during sleep, up to the partial reactivation of prefrontal regions during lucid REM sleep — that together may explain why lucid dream practice can plausibly affect motor performance, and under what conditions its effects appear to be more or less pronounced [3, 4, 5, 14, 15, 17].

To structure this synthesis, several research questions have been formulated. The first question concerns the degree of neural and functional overlap between imagined and executed actions, and the extent to which this overlap may be invoked to justify the very notion of mental practice as a non-trivial training modality, both in wakefulness and beyond it. The second question concerns the specific contribution of distinct sleep stages — particularly slow-wave sleep and REM sleep — to the consolidation and reorganisation of procedural memory traces relevant to motor performance. The third question concerns the neurobiological substrates of lucid dreaming itself, including the partial reactivation of prefrontal areas associated with metacognition and volitional control, the verifiability of the phenomenon through electrooculographic and neuroimaging methods, and the paradox of muscular atonia in the presence of preserved motor cortical activity. The fourth question addresses the behavioural and applied evidence on lucid dream practice in athletes, including the comparison with physical and mental practice, the role of intra-dream distractions and the immersive properties of the dream environment. The fifth and final question concerns the practical, methodological and ethical implications of integrating lucid dream practice into the work of coaching staff, sport psychologists and rehabilitation teams [5, 6, 7, 17].

Several caveats should be made explicit at the outset. The literature on lucid dream practice remains relatively small, with a limited number of laboratory-controlled trials and several conceptual and methodological challenges, including the low spontaneous frequency of lucid dreams, the variability of induction techniques, the difficulty of objectively quantifying intra-dream behaviour and the heterogeneity of motor tasks employed across studies [6, 7, 17]. The present review therefore adopts a narrative, rather than meta-analytic, format, and aims to map the conceptual terrain rather than to provide a definitive quantitative estimate of effect sizes. Throughout the text, cautious language has been preferred, and statements should be read as provisional syntheses of an evolving evidence base rather than as definitive claims. It is hoped that this synthesis may contribute to clarifying the theoretical foundations of lucid dream practice, to identifying directions for future empirical work — particularly polysomnographically controlled trials in elite cohorts — and to stimulating an informed, prudent discussion of its potential applications in contemporary sport and rehabilitation contexts [5, 6, 7, 8, 17].

2. Materials and Methods

2.1. Study design

The present work was conceived and executed as a narrative review, a methodological format particularly well suited to research questions that span several conceptually adjacent but methodologically heterogeneous domains. In contrast to systematic reviews and meta-analyses, which typically presuppose a relatively narrow clinical question and a body of comparable quantitative outcomes, narrative reviews allow for the integration of empirical and theoretical contributions drawn from neurophysiology, sleep medicine, cognitive psychology, sport sciences and clinical rehabilitation, even when the underlying study designs, populations and outcome measures differ substantially. Given that the intersection of motor imagery, sleep-dependent memory consolidation and lucid dream practice is characterised by a comparatively small empirical core, surrounded by a much larger conceptual and theoretical literature, this format was considered preferable to a strictly systematic synthesis.

The review was structured around a guiding question concerning the neurophysiological mechanisms by which imagery-based rehearsal — whether performed in wakefulness, during ordinary REM sleep or within the specific context of lucid dreaming — may contribute to the optimisation of procedural memory consolidation in athletes. Subsidiary questions, articulated in the introductory section, addressed the functional equivalence between imagined and executed actions, the role of distinct sleep stages in the offline reorganisation of motor memory traces, the neurobiology of lucid dreaming, the behavioural evidence on lucid dream practice in athletic populations and the practical implications of integrating such practice into coaching, sport psychology and rehabilitation work. The narrative format was retained throughout, with explicit acknowledgement of the provisional character of several syntheses and of the methodological limitations of the underlying primary literature.

The reporting framework was inspired, where pertinent, by methodological recommendations developed for narrative reviews of complex health-related topics, including the Scale for the Assessment of Narrative Review Articles (SANRA) and the methodological guidance derived from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Although PRISMA was not adopted in its entirety — which would be inconsistent with the narrative format — its principles regarding transparency of the search strategy, explicit specification of inclusion and exclusion criteria, and rigorous reporting of the synthesis process were applied. No formal protocol was registered, given the exploratory and conceptual character of the work, but a written internal plan was developed before the literature search was launched, specifying the conceptual map of the review, the thematic chapters to be covered, the databases to be queried and the criteria for inclusion. This document was used as an internal reference throughout the project and was revised twice during the search phase to accommodate emerging topics, in particular the literature on the cognitive neuroscience of lucid dreaming and on the role of distractions within lucid dream practice.

Given that all sources analysed in the review were already published peer-reviewed materials, no ethical approval was required, and no original data involving human participants or biological samples were collected. The review was conducted by a single author, with periodic consultation of supervisors at the conceptual and structural levels. Throughout the process, particular attention was paid to maintaining a critical stance towards the available evidence: rather than treating any single empirical study as definitive, individual findings were embedded into broader patterns and contrasted with convergent or divergent results from related work.

Where the literature was unequivocal, this was made explicit; where it was preliminary, fragmentary or methodologically limited, cautious language was used and the limitations of the evidence base were stated openly.

2.2. Literature search strategy

A targeted, multi-database literature search was conducted to identify peer-reviewed publications relevant to the topic. Four major bibliographic databases were queried — PubMed/MEDLINE, Scopus, Web of Science and Google Scholar — chosen for their complementary coverage of the biomedical, psychological, sport-science and neuroscientific literature. PubMed/MEDLINE provided access to the core biomedical and clinical literature, including sleep medicine and neurophysiology; Scopus and Web of Science were used to extend coverage into sport science, sport psychology and rehabilitation journals; Google Scholar was queried to identify additional grey-literature contributions, narrative reviews and recent open-access publications, particularly in journals that are not always fully indexed in the larger biomedical databases.

The search was conducted in iterative phases, beginning with broad conceptual queries and progressively narrowing towards more specific question-oriented searches. The first phase aimed at mapping the general landscape of the field and used relatively wide search strings combining keywords such as "motor imagery", "mental practice", "mental rehearsal", "visualisation", "sleep", "memory consolidation", "procedural memory", "REM sleep", "slow-wave sleep", "lucid dreaming", "lucid dream practice", "sport performance", "athletes" and "rehabilitation". Boolean operators (AND, OR, NOT) were used to combine these terms, and truncation as well as wildcards were applied where appropriate. The second phase introduced more focused queries oriented around specific subsections of the review, such as the neurobiology of lucid dreaming ("lucid dreaming AND prefrontal cortex", "lucid dreaming AND fMRI", "lucid REM sleep AND EEG"), the verification of lucid dreams ("lucid dreaming AND electrooculography", "eye signalling AND REM sleep") or the comparison between lucid dream practice and classical mental practice ("lucid dream practice AND finger tapping", "lucid dreaming AND motor learning").

A third phase consisted of citation chasing. The reference lists of central articles — particularly review papers, consensus statements and high-impact empirical studies — were screened by hand to identify additional relevant publications that had not surfaced through the initial keyword search. Where appropriate, "cited by" tools in Scopus and Google Scholar were used to identify more recent works that had built upon foundational studies. This snowballing procedure was particularly informative for the lucid dream literature, which is somewhat dispersed across journals dedicated to sleep research, consciousness studies, sport science and medical hypotheses, and where keyword searches alone may not exhaustively capture relevant contributions. A final, complementary phase consisted of targeted searches for Polish-language literature concerning sleep, mental training and rehabilitation in athletes, conducted via Google Scholar and the database of the Journal of Education, Health and Sport, which yielded additional national contributions to the evidence base.

No strict date restriction was applied. Given the historical depth of the literature on motor imagery and sleep, foundational papers dating back several decades were retained when they were considered seminal, while priority was given to publications from the last fifteen years for empirical evidence and from the last decade for review articles. The latest searches were conducted in early 2024. Only publications in English and Polish were considered, in line with the linguistic competence of the author; this language restriction is acknowledged as a limitation in the relevant subsection of the discussion. To ensure traceability, the bibliographic details of each retained source were exported to a dedicated reference-management workspace, and full-text versions of the articles were stored in a structured local repository for further reading and analysis.

2.3. Inclusion and exclusion criteria

Inclusion criteria were defined a priori, with the aim of balancing thematic relevance with methodological breadth. To be included, a publication had to satisfy several conditions. First, it had to be a peer-reviewed article, narrative or systematic review, consensus statement, book chapter or methodologically rigorous theoretical contribution published in a recognised scientific outlet. Second, its content had to be substantively relevant to at least one of the core themes of the review: (i) the neurophysiology and behavioural effects of motor imagery and mental practice in wakefulness; (ii) the architecture of sleep and its role in the consolidation of memory, with particular attention to procedural and motor memory; (iii) the neurobiology, phenomenology and induction of lucid dreaming; (iv) the use of lucid dream practice or related sleep-bound rehearsal techniques in athletic, clinical or rehabilitation contexts; or (v) the broader role of sleep, recovery and mental training in elite sport. Third, the study or article had to provide either original empirical data, a critical synthesis of the available evidence, or a clearly articulated theoretical framework that could meaningfully contribute to the narrative.

Exclusion criteria were similarly explicit. Publications that addressed sleep, dreaming or imagery only marginally, without a substantive engagement with the constructs of interest, were excluded. Non-peer-reviewed materials such as conference abstracts without subsequent full publication, dissertations not available in full text, opinion pieces in popular media and pre-print servers in fields outside the biomedical and sport-science domains were generally not considered, although a small number of contemporary preprints were retained for orientation when they reported information directly relevant to a rapidly evolving sub-topic. Articles whose full text was not retrievable through institutional access or open-access channels were excluded. Studies focused exclusively on pathological dream phenomena unrelated to lucid dreaming, on nightmare disorders or on sleep architecture in clinical sleep disorders without bearing on memory consolidation or sport performance were also excluded.

Particular attention was paid to clarifying the distinction between studies whose primary outcome was motor performance and studies in which sleep, dreaming or imagery were the primary focus. Both categories were retained when relevant, but the criteria for inclusion required that some explicit connection to the conceptual core of the review be articulated, whether through study design, sample characteristics, theoretical framing or discussion. Studies whose populations were predominantly clinical (e.g. stroke survivors, patients with traumatic brain injury) were retained when their findings illuminated mechanisms that may extend, by analogy, to athletic populations, particularly in the context of rehabilitation; such transfer was nevertheless treated with caution and made explicit in the relevant chapters.

The selection process was iterative. Titles and abstracts of identified records were screened against the inclusion and exclusion criteria, and potentially eligible articles were retrieved in full text for a second-pass evaluation. In ambiguous cases, judgement was guided by the degree to which the article addressed the conceptual map of the review and by the methodological quality of the study, with priority given to publications appearing in journals with established editorial standards. Articles ultimately retained in the synthesis are reflected in the reference list. No formal quantitative assessment of risk of bias was conducted, given the narrative format and the heterogeneity of study designs; however, methodological limitations of individual studies (small samples, lack of polysomnographic verification, self-report measures, limited generalisability to elite athletes) were considered when integrating their findings into the synthesis.

2.4. Data synthesis

Given the narrative character of the review and the conceptual heterogeneity of the underlying literature, data synthesis was performed in a qualitative, thematic manner, rather than through a meta-analytic aggregation of effect sizes. The synthesis was organised around the conceptual map established at the beginning of the project, which closely follows the architecture of the present manuscript: the neurophysiological foundations of motor imagery in wakefulness; the architecture of sleep and the offline consolidation of motor memory; the neurobiology and phenomenology of lucid dreaming; the behavioural and applied evidence on lucid dream practice in athletes; and the practical implications, limitations and risks of integrating such practice into the training and rehabilitation routines of competitive athletes.

For each chapter, the retained sources were first read in full, then summarised in a structured internal note that included the study design, sample characteristics, principal findings, methodological caveats and a short reflection on the relevance of the source to the corresponding chapter. These notes were then compared and contrasted across studies, with the aim of identifying convergent patterns, divergences and gaps in the evidence base. Where several independent sources converged on a similar conclusion, this convergence was made explicit. Where findings were contradictory or limited by methodological constraints, the divergence was reported and contextualised, and cautious language was used in the corresponding sections of the manuscript. Where the literature was sparse — for instance, in the case of laboratory-controlled trials of lucid dream practice in elite athletes — this scarcity was openly acknowledged, and the resulting synthesis was framed as provisional and as a stimulus for further empirical work.

Conceptually, the synthesis was guided by a layered approach. At the most basic level, attention was paid to the descriptive content of the literature: what phenomena have been observed, in which populations, with which measurement tools and under which experimental conditions. At a second level, the synthesis sought to identify the mechanistic frameworks proposed by various authors — for instance, the functional equivalence hypothesis in the imagery literature, the active system consolidation hypothesis in the sleep literature, and the model of partial prefrontal reactivation in the lucid dreaming literature — and to evaluate how well these frameworks could be integrated into a coherent narrative about sleep-bound rehearsal. At a third, more applied level, the synthesis considered how the available evidence might be translated into practical recommendations for coaches, sport psychologists, physiotherapists and athletes, while remaining alert to the risks of overinterpreting an evidence base that is still evolving.

In line with the narrative format, no quantitative pooling of effect sizes was attempted. However, where the literature reported numerical outcomes — for instance, the percentage of overnight improvement in finger-tapping performance after sleep, the proportion of frequent lucid dreamers within athletic populations or the relative magnitude of intra-dream time distortions — these figures were reported in the manuscript with their original references, in order to give the reader a concrete sense of the empirical evidence. Throughout the synthesis, particular care was taken to avoid presenting preliminary findings as definitive, and to differentiate between robust observations supported by multiple independent studies and tentative results derived from single studies with small samples.

3. Neurophysiological foundations of motor imagery training in wakefulness

3.1. Modalities and Perspectives in Motor Imagery

Motor imagery has been defined in the contemporary literature as a dynamic mental state during which the representation of a given motor act or movement is internally rehearsed in working memory in the absence of any concomitant overt motor output [3, 22]. The construct emerged in the second half of the twentieth century at the intersection of cognitive psychology, neuropsychology and sport psychology, and has gradually crystallised around a relatively narrow conceptual core: the deliberate, conscious simulation of a motor action that, while sharing many representational features with the corresponding overt movement, is not realised in observable behaviour [3, 4, 19]. Within this framework, motor imagery practice — sometimes used interchangeably with the older term "mental practice" — refers to the systematic, repeated use of motor imagery for the purposes of skill learning, performance enhancement or rehabilitation, typically organised into structured rehearsal sessions and embedded within a wider training programme [1, 2, 22, 24].

A fundamental conceptual distinction within the motor imagery literature concerns the two principal modalities in which imagery is generally expressed: visual imagery and kinesthetic imagery [19, 20]. Visual imagery designates the mental "seeing" of a movement, in which the imager generates a quasi-perceptual representation that resembles, in its phenomenology and in its underlying neural recruitment, the experience of watching a movement unfold [3, 19]. Kinesthetic imagery, by contrast, designates the mental "feeling" of a movement, in which the imager focuses on the proprioceptive, somatosensory and motor sensations associated with executing the action, including muscular contractions, joint amplitude, postural adjustments and the perceived weight or resistance of any equipment involved [19, 20, 27]. Although these two modalities can be deployed independently, in everyday practice they are frequently combined, and a growing methodological consensus underlines the importance of clearly specifying which modality (or which combination) is being elicited in any given experimental or applied intervention [3, 19, 26].

The visual modality may itself be deployed from two distinct perspectives, traditionally referred to as the first-person and third-person perspectives [2, 3, 21]. In a first-person, or "internal", visual imagery perspective, the imager mentally adopts the position of the agent, as if equipped with a camera mounted on their own head, and visualises the movement from the inside out [2, 21, 25]. In a third-person, or "external", visual imagery perspective, the imager mentally takes the position of a spectator, observing themselves (or another person) performing the action from a vantage point that is external to the body [3, 21]. The two perspectives differ not only in their phenomenological character but also in their cognitive and neural underpinnings, with positron emission tomography work indicating that third-person perspective simulation engages right inferior parietal regions, the precuneus, the posterior cingulate cortex and frontopolar areas to a greater extent than the first-person condition, while first-person perspective simulation preferentially recruits the left inferior parietal lobule and the somatosensory cortex, which have been linked to the programming of self-generated actions [21].

In the sport-psychology literature, the relative merits of these perspectives have been the subject of long-standing debate [3, 25]. Some authors have argued that internal (first-person) visual imagery may be especially advantageous because it approximates the natural egocentric experience of performing a movement and may therefore facilitate a more accurate cognitive simulation of the actual perceptual–motor sequence [2, 25]. Other authors, however, have noted that external (third-person) imagery may be more useful for "form-based" skills, such as gymnastics floor routines or technical elements in figure skating, where the precision of body shape and the spatial trajectory of the limbs are critical for performance [3]. An experimental study conducted in basketball players, for instance, reported that internal imagery training was associated with superior free-throw accuracy compared with an external imagery condition, particularly when combined with high attentional concentration, with a posttest mean difference of approximately four points in favour of the internal imagery group [25]. The consensus that has emerged in narrative reviews tends to favour internal visualisation as the default, while acknowledging that external imagery retains a complementary role in technical learning, in error detection and in the early stages of skill acquisition [2, 3]. Importantly, it has been shown that kinesthetic imagery may be combined with either perspective: although first-person visual imagery and kinesthetic imagery are often used together, the literature now contains evidence that kinesthetic representations may also be accessed from an external visual vantage point, particularly when the form of the movement is the primary focus [3].

Several psychometric instruments have been developed to characterise individual differences in imagery ability [3, 26]. The Movement Imagery Questionnaire and its revised versions (MIQ-R and MIQ-RS), as well as the Vividness of Motor Imagery Questionnaire-2 (VMIQ-2), have been widely used to assess external visual, internal visual and kinesthetic imagery vividness on Likert-type scales [6, 19, 23]. In Polish-language sport psychology, the Sports Imagery Ability Measure (SIAM) has likewise been introduced as a multidimensional instrument capturing the vividness, controllability and modality breadth of imagery in athletes, and has been applied in introductory case work with young swimmers, who showed improvements in all SIAM subscales after structured imagery training [26]. Chronometric measures, in which the time required to imagine a movement is compared with the time required to physically execute the same movement, provide a complementary, more objective indicator of imagery quality and have been used to identify "good imagers" — individuals who are able to preserve the temporal characteristics of their imagined actions relative to the corresponding overt movements [3, 19, 24]. Combined approaches that integrate self-report questionnaires, chronometric scores and autonomic measures are now considered to offer a more reliable estimate of imagery ability than any single instrument, particularly in studies that aim to select participants with very good to excellent imagery skills [19].

Brain-imaging work using functional magnetic resonance imaging has further differentiated visual and kinesthetic motor imagery at the neural level. In a key study employing 3 Tesla fMRI in skilled imagers, both visual and kinesthetic imagery were associated with activations overlapping those of physical execution — including motor-related regions and parietal lobules — yet a direct contrast revealed a clear divergence: visual imagery preferentially activated occipital regions and the superior parietal lobules, whereas kinesthetic imagery yielded stronger activation in motor-associated structures and the inferior parietal lobule [19]. Complementary work using functional near-infrared spectroscopy during a hand laterality judgement task indicated that kinesthetic imagers tend to recruit the dorsolateral prefrontal cortex, premotor cortex, supplementary motor area, primary motor cortex and parietal cortex more extensively than visual imagers, with particularly elevated activation in the frontal eye fields, primary somatosensory cortex, primary motor cortex and inferior parietal lobule [20]. Together, these data suggest that visual and kinesthetic imagery may be mediated, at least partly, by separable neural networks, and that the choice of modality may have non-trivial implications for the kind of cognitive and motor processes that are mobilised during practice [19, 20].

The relevance of this differentiation extends beyond the laboratory. In applied sport psychology, the PETTLEP model — an acronym standing for Physical, Environment, Task, Timing, Learning, Emotion and Perspective — has been developed as a theoretically grounded checklist for designing motor imagery interventions, with explicit attention to the modality and perspective of imagery, the physical posture and equipment of the athlete during practice, and the affective and contextual factors that may modulate the realism of the simulation [3, 23]. Work conducted in elite female ice hockey players using magnetoencephalography has shown that PETTLEP-guided complex motor imagery, involving multifaceted "open-sport" scenarios, can reliably activate a posterior left-hemisphere cortical region surrounding the intraparietal sulcus, a structure also engaged in the integration of visuomotor information and in the programming of complex actions [23]. Such findings underline that the choice of modality, perspective and contextual richness of imagery practice is not a peripheral methodological concern but rather a determinant of the neural processes that are recruited during rehearsal, and therefore of the potential transfer of training effects to subsequent performance [2, 3, 23].

Beyond the standard dichotomy between visual and kinesthetic imagery, several authors have argued for an expanded conceptualisation that acknowledges the multimodal character of mental imagery [2, 22, 26]. From this perspective, imagery is not confined to a single sense but may integrate auditory, tactile, olfactory and even gustatory components, particularly in complex sport situations where the perception of crowd noise, the surface of an instrument or the breathing pattern of a teammate may all contribute to the realism of the simulation [2, 26]. The literature on visualisation in elite sport emphasises that, to maximise efficacy, imagery practice should engage the major sensory modalities and should incorporate elements of perspective, emotion, environment, task and timing, in line with the recommendations of the PETTLEP framework [2, 23, 26]. Although this multisensory enrichment increases the cognitive demand of the practice, it appears to enhance the functional resemblance between the imagined and the executed action, and may therefore strengthen the underlying processes of motor learning [2, 22, 24].

3.2. Functional Isomorphism and Neural Substrates

The theoretical bridge that links the behavioural benefits of motor imagery to its neural underpinnings is commonly referred to as the functional equivalence hypothesis, sometimes also called the principle of functional isomorphism [3, 22, 23]. Although various formulations of this hypothesis differ in their details, the core proposition is that imagined and executed actions share, to a substantial degree, the neural structures and representational formats that subserve motor planning, motor preparation and motor control [3, 19, 24]. From this perspective, motor imagery is not a marginal cognitive curiosity but a genuine form of motor simulation, which engages many of the same neural circuits as overt action, albeit in a modulated and partially "scaled-down" mode that prevents the actual issuance of effective motor commands to peripheral effectors [3, 4].

Neuroimaging work conducted over the past three decades has provided convergent evidence in favour of functional isomorphism [3, 4, 19, 22, 24]. Positron emission tomography and fMRI studies have repeatedly identified activations in the premotor cortex, supplementary motor area (SMA), pre-SMA, posterior parietal cortex (including both inferior and superior parietal lobules), basal ganglia and cerebellum during motor imagery, with topographies that broadly overlap those observed during the actual execution of the same movements [4, 19, 22]. The supplementary motor area, in particular, appears to play a central role in the timing, monitoring and preparation of complex movements, and has been consistently activated during the rehearsal of finger sequences, locomotor patterns and sport-specific skills, both in the posterior SMA proper and in the more anterior pre-SMA region [5, 19, 20]. The premotor cortex, encompassing both dorsal and ventral subdivisions, has been linked to the selection and sequencing of motor programmes and is similarly recruited during the covert simulation of action [19, 20, 22].

The role of the primary motor cortex during motor imagery has been the subject of greater controversy [19, 22]. Some early studies failed to detect peak activations in this region during purely imagined movement, suggesting that primary motor cortex involvement was restricted to overt action [19]. More recent work, however, has reported fleeting or partial activations in the anterior part of the primary motor cortex during motor imagery, particularly when the imager focuses on kinesthetic components or rehearses complex sequences [19, 20]. It has been proposed that the cluster distribution in the anterior primary motor cortex may be significantly reduced during imagery compared with execution, while the posterior part remains similarly engaged, and that the involvement of this area in imagery may relate to non-executive functions such as spatial encoding rather than to the issuance of motor commands [19]. Convergent evidence from transcranial magnetic stimulation work has shown that imagined movements modulate corticospinal excitability, with subthreshold motor commands appearing to influence spinal cord activity even in the absence of overt motion, and that this modulation tends to be more pronounced in individuals with higher imagery ability [22, 24].

The cerebellum and basal ganglia have been consistently implicated in the motor imagery network, although with some topographic differences relative to overt execution [19, 22]. Cerebellar activations during imagery tend to be more posterior and inferior than those observed during actual movement, a pattern that may reflect a selective involvement of cerebellar regions associated with internal models and predictive simulation rather than with the on-line control of motor output [19]. Within the basal ganglia, the putamen has been highlighted as a particularly relevant structure, with studies of basal ganglia dysfunction underscoring its role in the neural circuitry that mediates motor imagery [4, 19]. Parietal cortex involvement is also robust, with both the superior parietal lobule and the intraparietal sulcus contributing to the generation of mental images of action, the integration of body-related information and the manipulation of spatial reference frames [19, 20, 23].

It should be emphasised, however, that functional isomorphism is not equivalent to functional identity [3, 22]. While imagined and executed actions share a substantial portion of their neural substrates, there are also areas that are differentially activated by one process and not the other [3, 19, 22]. Some brain regions, particularly those involved in higher-level cognitive control, may show stronger activation during imagery than during overt execution, perhaps reflecting the additional working memory and attentional demands of internal simulation [20, 22]. Conversely, certain regions involved in the on-line control of movement — including parts of the primary motor cortex, the sensorimotor cortex and the cerebellum — may show weaker or differently configured activations during imagery, in keeping with the fact that imagined movements do not generate overt motor output [19]. The metaphor of motor imagery as a "scaled-down" version of motor execution thus captures part of the picture, but it must be complemented by an appreciation of the genuine architectural differences between covert and overt action [3, 22].

A particularly informative experimental approach has been to contrast motor imagery from first-person and third-person perspectives within the same paradigm [21]. The PET investigation of perspective taking during action simulation reported that both first-person and third-person conditions engaged a common set of structures, including the SMA, precentral gyrus, precuneus and the MT/V5 complex, but that the third-person condition recruited the right inferior parietal lobule, precuneus, posterior cingulate cortex and frontopolar regions more strongly, whereas the first-person condition preferentially engaged the left inferior parietal lobule and somatosensory cortex [21]. These results are consistent with a view in which a common motor simulation network supports both perspectives, while additional brain regions are differentially recruited depending on the perspective adopted and on the cognitive demands of self–other distinction [21, 23].

Behavioural evidence complements these neuroimaging findings [3, 24]. Mental chronometry studies have repeatedly demonstrated that the time required to imagine a movement closely tracks the time required to execute the same movement, and that Fitts's law — which states that more difficult movements take longer to perform — also appears to apply to imagined motion [3]. When task difficulty is increased, for example by asking participants to walk while imagining the carrying of a heavy load, the duration of imagined motion increases accordingly [3]. Such temporal isomorphism is generally taken as behavioural evidence that imagined actions share kinematic properties with their overt counterparts, although the literature acknowledges that this temporal correspondence is not always perfect and may be modulated by task complexity, instructions, attentional focus and the imagery modality employed [3, 16]. Comprehensive reviews of behavioural and neuroimaging studies have proposed that the benefits of motor imagery practice should be understood as encompassing both online and offline learning processes [24]. Online processes refer to the immediate performance gains observed during or shortly after a session of imagery practice, while offline processes refer to delayed improvements that emerge after a latent period — most notably after a night of sleep — in the absence of further training [14, 16, 24]. The functional isomorphism between imagined and executed actions provides the conceptual scaffold for online effects, in the sense that repeated covert activation of motor circuits may strengthen the relevant synaptic pathways in a manner analogous to physical practice [22, 24]. Offline effects, by contrast, appear to depend additionally on the consolidation processes that unfold during sleep, a theme that will be developed in Chapter 4 [14, 15, 16].

Mechanistic frameworks proposed in the cognitive rehabilitation literature converge with these neurophysiological observations [4]. The psychoneuromuscular theory of motor imagery, for instance, posits that imagery activates neural pathways similar to those used in actual movement, leading to neuromuscular activations that are similar to, although weaker than, those produced by overt motion [4]. Repeated use of such pathways may strengthen them through Hebbian-type mechanisms, in a manner consistent with classical theories of synaptic plasticity [4, 22]. Other frameworks, such as the symbolic learning theory and the bioinformational theory, emphasise the role of imagery in constructing and refining cognitive representations of movement, while Grush's emulation theory has gained increasing traction by proposing that motor imagery is driven by an internal "simulator" within the brain's motor control system [4]. Although these frameworks differ in their specific commitments, they share a fundamental insight that aligns with the functional isomorphism hypothesis: imagined movements are not mere abstract representations divorced from the motor system, but rather genuine simulations that engage and modulate the same circuits responsible for overt action [4, 22].

Considered together, the neurophysiological evidence on functional isomorphism provides the cornerstone of the rationale for using motor imagery as a training tool [3, 22, 24]. If imagined and executed movements share a substantial portion of their neural substrates, then the repeated covert rehearsal of a motor skill may plausibly induce some of the neuroplastic changes that are observed after physical practice [22, 24]. This rationale has motivated the integration of motor imagery into the preparation routines of elite athletes, the rehabilitation programmes of stroke survivors and patients with traumatic brain injury, and, more recently, the speculative extension of mental practice into the dreaming brain [4, 5, 22]. The strength of the evidence varies across these domains, but the underlying logic is consistent: the brain, far from being a passive bystander during covert rehearsal, appears to engage many of the same circuits that it would deploy during overt action, and this engagement may form the basis of measurable behavioural benefits [3, 22, 24].

3.3. Autonomic Responses and Peripheral Activation

A particularly compelling line of evidence for the "reality" of imagined movement, from the perspective of the nervous system, comes from studies of the autonomic nervous system (ANS) [19, 22]. If motor imagery were a purely cognitive or representational process, decoupled from the motor and visceral systems, one would not expect to observe systematic, action-specific changes in autonomic parameters during purely imagined movement [3, 22]. The available evidence, however, points clearly in the opposite direction: imagined actions are routinely accompanied by autonomic responses that mirror, in their direction and often in their magnitude, those observed during the corresponding overt movements [3, 19, 22].

Heart rate is among the most studied autonomic variables in this context [3, 5, 19]. Several investigations have reported that imagined exercise — for instance, imagined cycling, running or weightlifting — is associated with elevations in heart rate that scale with the perceived intensity of the imagined effort, in a manner reminiscent of the relationship observed during actual exercise [3, 19]. Pulmonary ventilation and respiratory frequency follow a similar pattern, with imagined exertion producing increases in respiratory rate and minute ventilation that, while typically smaller than those observed during overt exertion, are nevertheless statistically distinguishable from baseline [3, 19]. Systolic blood pressure has also been reported to rise during imagery of strenuous movements such as dumbbell lifting, and similar findings have been observed for skin electrodermal activity and thermovascular responses, suggesting a generalised activation of sympathetic outflow during motor simulation [19].

The mechanisms underlying these autonomic responses are thought to involve central command — the descending neural signal originating in the cortical and subcortical motor structures that, during overt exercise, contributes to the recruitment of cardiovascular and respiratory adjustments in anticipation of, and in parallel with, motor output [3, 22]. According to this view, motor imagery activates central command in a manner that is sufficient to produce measurable autonomic adjustments, even though the descending motor signal is not converted into overt motor execution at the level of the spinal cord and peripheral effectors [3, 19, 22]. The release of catecholamines, including adrenaline and noradrenaline, has been documented during imagery of vigorous exercise in some studies, providing biochemical evidence of sympathoadrenal activation during covert rehearsal [3, 19].

The implication of these findings is far-reaching [3, 22]. From the perspective of the autonomic nervous system, imagined movement is not a purely "virtual" event but rather a physiological event that engages many of the same regulatory pathways as overt motor activity [19, 22]. This observation aligns with the broader functional isomorphism hypothesis: if the central motor command is activated, the autonomic adjustments that it normally triggers — heart rate increase, respiratory acceleration, sympathoadrenal activation — are likewise engaged, although in attenuated form [3, 19]. In this sense, the nervous system appears to treat imagined movement as a "real" motor event, at least in the sense that it deploys the same anticipatory adjustments that it would deploy in preparation for, or during, overt exercise [19, 22].

These autonomic findings have been used in the methodological literature to develop quantitative measures of imagery ability [19]. In studies by Guillot and colleagues, autonomic indicators such as skin resistance responses and tonic arousal levels have been combined with psychometric and chronometric measures to generate composite imagery ability scores, which appear to discriminate effectively between high and low imagers [19]. High imagers, who report vivid and controllable mental images, tend to display autonomic responses during imagery that are closer in magnitude to those observed during overt action, while low imagers exhibit weaker autonomic activation [19]. The use of such physiological markers may help to overcome some of the methodological limitations of purely subjective imagery assessments, and may inform the design of more rigorous experimental and applied interventions [3, 19].

The autonomic response to imagery is not limited to cardiorespiratory variables [22, 27]. Studies of electromyographic (EMG) activity have shown that imagined movements may be accompanied by subthreshold muscle activations in the corresponding limbs, particularly when kinesthetic imagery is employed [19, 22]. While these activations are insufficient to produce visible motion, they appear to reflect the partial descent of the motor command towards peripheral effectors [22]. Corticospinal excitability, as assessed by transcranial magnetic stimulation, is also modulated by motor imagery, with imagined contractions producing increases in motor evoked potentials that tend to be graded with the imagined force level [22, 24]. Together, these findings suggest that the motor system, including its peripheral components, is engaged in a graded and task-specific manner during motor imagery, and that this engagement may underlie at least part of the training-related effects of imagery practice [22, 24, 27].

Closely linked to autonomic engagement is the modulation of proprioceptive function during imagery practice [27]. Work conducted in karate athletes has reported that an 8-week motor imagery training programme, implemented in parallel with regular kumite training, was associated with substantial improvements not only in target-oriented punching accuracy and in motor imagery skills (both kinesthetic and visual), but also in proprioceptive performance, including joint reposition accuracy [27]. The authors of that study argued that an effectively implemented imagery programme may go beyond the mental rotation of images and may influence the autonomic nervous system, potentially triggering electrical currents in muscle groups that subserve proprioceptive feedback loops [27]. Although such inferences should be interpreted cautiously given the modest sample size, they are coherent with the broader picture of motor imagery as a process that engages not only central cortical structures but also peripheral physiological systems relevant to skilled movement [22, 27].

The clinical and applied implications of these autonomic findings are not trivial [22, 24, 27]. In sport psychology, the documented cardiorespiratory responses to imagery support the use of motor imagery as an adjunct to physical training, particularly during periods of injury, illness or competitive tapering, when reduced training loads may otherwise compromise the maintenance of cardiovascular adaptations [8, 22]. Although imagery alone is not a substitute for actual physical conditioning, the observation that it elicits measurable autonomic responses suggests that it may play a complementary role in preserving certain components of the cardiovascular response to effort [3, 22]. In rehabilitation contexts, the autonomic engagement during imagery may contribute to the maintenance of trophic and regulatory inputs to muscles that cannot be voluntarily contracted, supporting the use of imagery in post-stroke or post-injury rehabilitation programmes [4, 22, 24].

It is important to maintain a cautious interpretation of these findings [3, 19, 22]. The autonomic responses to imagery are typically smaller than those produced by overt exercise, and their magnitude is influenced by individual differences in imagery ability, by the modality and perspective of the imagery, and by the contextual realism of the practice setting [19]. Furthermore, not all studies have replicated the same patterns of autonomic activation, and methodological differences in the measurement of cardiorespiratory and electrodermal parameters complicate cross-study comparisons [3, 19]. Nevertheless, the convergent evidence from multiple laboratories and across multiple autonomic variables provides a reasonably robust empirical basis for the claim that motor imagery is a physiologically "real" event for the nervous system, and that this physiological reality may underlie at least part of its effectiveness as a training modality [3, 19, 22, 24].

In sum, the autonomic data provide a third pillar of evidence — alongside neuroimaging and behavioural findings — for the functional equivalence between imagined and executed actions [3, 19, 22]. The temporal congruence of mental chronometry, the topographic overlap of cortical and subcortical activations, and the systematic autonomic responses converge to support the view that motor imagery engages the same network of neural and physiological mechanisms that subserve overt motor performance [3, 19, 22, 24]. This convergence forms the empirical and conceptual foundation upon which the subsequent chapters will build, as the present review moves from the well-characterised domain of motor imagery in wakefulness to the more speculative, but increasingly studied, terrain of mental rehearsal during sleep, and ultimately to the specific case of motor practice within lucid dreams [5, 16, 17].

4. Sleep architecture and the phenomenon of memory consolidation (the offline dialogue)

4.1. Sleep in Sport: Deprivation, Quality, and Performance

Sleep is increasingly conceptualised in contemporary sport science as an active biological process that supports physical recovery, cognitive functioning and the consolidation of learned skills, rather than as a passive interruption of waking activity [8, 11, 13]. From this perspective, sleep represents a determinant of athletic performance that is, at least in principle, modifiable through targeted hygiene and behavioural interventions, and that may complement more conventional recovery strategies such as nutrition, hydration and physical regeneration [8, 9, 12]. The consensus statement on recovery and performance issued by an international panel of sport scientists explicitly identifies sleep as one of the pillars of physiological and psychological recovery, alongside cognitive self-regulation, periodised loading and tailored recovery modalities [8].

The mechanistic basis for these claims is supported by a converging body of evidence from sport-medicine reviews. A systematic review by Bartkowska and colleagues, focusing on the relationship between sleep parameters and sports injuries, identified strong evidence that insufficient or fragmented sleep is associated with an elevated risk of musculoskeletal injury, mediated by impaired cognitive functioning, slowed reaction time, weakened neuromuscular control, increased systemic inflammation and impaired tissue regeneration [9]. The same authors articulate the notion of sleep as an "ergogenic supplement", arguing that experimental sleep extension, for instance in collegiate basketball players, has been associated with improved sport-specific performance and increased daytime alertness, with effects that compare favourably with several conventional ergogenic strategies [9]. A complementary systematic review by Białeta and colleagues reaches a similar conclusion, emphasising that adequate sleep duration and quality are associated with improved reaction time, mood regulation, cognitive performance and physical readiness, while sleep restriction has been linked to detrimental effects on aerobic and anaerobic outputs, perceived exertion and the consistency of skill execution [10].

The empirical picture of how athletes actually sleep, however, is less encouraging. Kölling and colleagues, in a brief but comprehensive review, report that elite athletes commonly sleep below the recommended 7–9 hours per night, with mean sleep durations around 6.8 hours in mixed cohorts of individual and team-sport competitors, and even shorter durations in disciplines such as swimming, cycling and race walking [11]. Approximately half of the elite or highly trained team-sport athletes assessed in questionnaire-based studies have been classified as poor sleepers, and a clinically significant proportion present features compatible with daytime sleepiness or sleep-disordered breathing [11]. Several contextual factors appear to contribute to these patterns, including the scheduling of training and competition (late-night games, early-morning practices, intercontinental travel and jet-lag), pre-competitive anxiety, occupying thoughts and the increasing use of electronic devices before bedtime, which may disrupt melatonin secretion through blue-light exposure and may foster emotional arousal through stimulating social-media content [11]. A Polish narrative review by Frydrych-Szymonik and colleagues converges on these conclusions, arguing that sleep disturbances among athletes often stem from insufficient knowledge of sleep hygiene and that lifestyle-based interventions, including properly scheduled regenerative naps, may meaningfully support recovery [12].

The functional consequences of suboptimal sleep extend beyond fatigue. Fabian and colleagues emphasise that chronic sleep restriction is associated with a loss of functional connectivity between the medial prefrontal cortex and the amygdala, with a relative disinhibition of amygdala activity, increased emotional reactivity and a measurable impairment in moral and social judgement [13]. The same review notes that sleep deprivation may compromise neurotransmitter dynamics, particularly involving noradrenaline, serotonin and histamine, with downstream effects on memory encoding, language processing and decision-making [13]. In the context of competitive sport, where reaction time, decision-making under uncertainty and the regulation of arousal and emotion are central to performance, even modest sleep restriction may translate into perceptible, although not always statistically significant, decrements in performance outcomes [10, 11, 13].

Beyond performance, the protective effect of sleep against injury is supported by both biomechanical and physiological considerations. Adequate sleep appears to facilitate tissue repair via increases in nocturnal growth hormone secretion, to support immune function via the regulation of pro- and anti-inflammatory cytokines, and to attenuate the rise in catabolic hormones that would otherwise oppose recovery from training stimuli [9, 13]. Reaction time and neuromuscular control, both of which depend on sleep-dependent restoration of cortical and subcortical functioning, are particularly vulnerable to acute sleep deprivation and chronic sleep restriction, with implications for sports where rapid decision-making and coordination are critical, such as combat sports, team sports and racket sports [9, 10, 11]. Although the literature acknowledges that the magnitude of these effects is variable across studies and that some forms of gross motor performance appear relatively resistant to short-term sleep loss, the overall pattern is consistent with a model in which sleep functions as a multidimensional support system for the athlete [10, 11].

Within this framework, the relevance of sleep for procedural memory consolidation acquires particular salience. As noted by Kölling and colleagues, "memory consolidation is a function of sleep that is especially important for athletes in terms of learning procedural skills" [11]. From a theoretical standpoint, this places sleep at the very centre of the dialogue between physical practice and skill acquisition, a position that has been increasingly emphasised in narrative and systematic reviews over the past two decades [14, 15, 24]. The remainder of the present chapter is devoted to a more detailed exposition of the architecture of sleep, of the differential roles of slow-wave and REM sleep in cognitive and motor processes, and of the mechanisms through which the brain is thought to consolidate, reorganise and protect newly acquired motor memories during the night.

4.2. Sleep Architecture: Differential Roles of SWS and REM Sleep

Sleep is not a homogeneous state but rather a cyclic alternation of distinct stages, each characterised by specific electroencephalographic, electromyographic, electrooculographic and neurochemical signatures [11, 13, 15]. In humans, sleep is conventionally classified into non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep, with NREM sleep further subdivided into three stages (N1, N2 and N3) according to current scoring criteria, corresponding to increasing depth of sleep [11, 15, 29]. These stages cycle every 90 minutes or so across the night, with NREM stages 3 and 4 — collectively referred to as slow-wave sleep (SWS) — dominating the first half of the night, while stage 2 NREM and REM sleep prevail during the latter half [14, 15, 29].

Each stage is associated with characteristic neural oscillations. Stage 2 NREM is marked by phasic events including K-complexes (large electrical sharp waves) and sleep spindles (short synchronised 7–14 Hz oscillations, with most contemporary studies adopting an 11–16 Hz window), while SWS is dominated by low-frequency slow oscillations (0.5–4 Hz, with a particular emphasis on the <1 Hz band) reflecting widespread cortical synchrony [15, 29, 33]. During REM sleep, electroencephalographic activity becomes desynchronised again and high-frequency oscillations in the gamma range (30–80 Hz) re-emerge in a pattern more reminiscent of wakefulness; phasic bursts of rapid eye movements appear, and skeletal muscle tone is markedly reduced, producing the characteristic atonia of this stage [15, 17, 29]. Neurochemically, NREM sleep is associated with reduced activity of subcortical cholinergic, serotonergic and noradrenergic systems, whereas REM sleep features a near-suppression of aminergic outflow alongside cholinergic activation that may equal or exceed waking levels [15, 29].

The functional significance of these stages for memory and cognition has been the subject of decades of research. Diekelmann and Born proposed that SWS and REM sleep support, respectively, system consolidation and synaptic consolidation, through distinct but complementary patterns of neuromodulatory activity and field-potential oscillations [15]. According to this framework, SWS supports the redistribution of hippocampus-dependent memories towards neocortical sites through the orchestrated interaction of slow oscillations, spindles and hippocampal sharp-wave ripples in a context of minimal cholinergic activity, whereas REM sleep — characterised by high cholinergic and theta activity and by local upregulation of plasticity-related gene expression — may favour the synaptic consolidation of memories in the cortex [15, 30]. Walker and Stickgold, in an earlier comprehensive review, similarly emphasised that "sleep itself cannot be treated as a homogeneous state, which either does or does not affect memory", but rather possesses a range of physiological and neurochemical mechanisms that can differentially contribute to memory consolidation [29].

The literature on REM sleep and memory has been historically more contentious than that on NREM sleep. Siegel offered an influential critique of the REM-sleep–memory-consolidation hypothesis, arguing that animal and human studies linking REM sleep duration with learning had produced inconsistent results, that pharmacologically or surgically induced REM-sleep suppression in humans had not consistently produced memory deficits, and that the time spent in REM sleep did not correlate with learning ability across species or with encephalisation, raising doubts about a strict causal role for REM sleep in memory consolidation [28]. Subsequent work, however, has tended to qualify rather than refute the involvement of REM sleep in memory processes. Walker and Stickgold note that, while REM sleep may not be necessary for the consolidation of simple, emotion-free declarative associations, a substantial body of evidence supports its role in the consolidation of complex, emotionally salient declarative memories embedded in pre-existing associative networks, in the generation of insight and in the flexibility of cognitive processing [29]. More recent reviews suggest that REM sleep may also contribute to specific forms of motor memory and to the integration and generalisation of memories across pre-existing semantic networks, although the precise mechanisms remain incompletely understood [15, 30].

The contribution of sleep architecture to motor memory consolidation has been investigated using both classical laboratory tasks and complex sport-specific motor learning paradigms. In the well-known finger-tapping study by Walker and colleagues, overnight improvement in motor speed correlated significantly with the percentage of stage 2 NREM sleep, particularly in the last quarter of the night, with as much as 52% of the inter-subject variance in overnight improvement explained by this single sleep parameter [14, 29]. Other authors have reported associations with REM sleep, especially for more complex tasks, suggesting that the specific sleep stage involved in consolidation may depend on task complexity and on the type of motor representation engaged [29, 36]. Erlacher and colleagues, for example, examined the influence of a complex motor learning session (trampolining) on subsequent sleep architecture, reporting changes in REM sleep parameters in the night following motor learning compared with a control task without a substantial learning component; the effects, although smaller than in earlier studies, were consistent with the hypothesis that REM sleep — particularly rich in the morning hours — plays a role in the consolidation of complex procedural skills [36]. Such findings have been interpreted as suggesting that REM sleep should not be unnecessarily curtailed after complex motor learning sessions, a recommendation with practical relevance for athletes whose training schedules may inadvertently truncate the late part of the night [36].

Sleep stage architecture also appears to mediate the consolidation of motor skills learned through covert practice modalities, including motor imagery and action observation. In a recent EEG-based study, Conessa and colleagues reported that a daytime nap supported the retention of finger-tapping sequences learned through physical practice and motor imagery, and the inter-manual transfer of skill after action observation, with sleep spindle activity organised in a temporal cluster-based pattern across all practice modalities [33]. Together, these studies suggest that the differential contributions of NREM and REM sleep to motor memory consolidation should be interpreted in light of the specific task, the encoding modality and the temporal proximity between practice and sleep [29, 33, 34, 36].

4.3. Offline Consolidation of Motor Memory

A central tenet of contemporary motor learning research is that performance improvements continue to accrue in the absence of further practice, particularly across a period of sleep — a phenomenon commonly referred to as offline learning or offline consolidation [14, 16, 24, 29]. As Walker and Stickgold note, classical accounts of memory consolidation emphasised stabilisation against interference, while more recent work has extended the concept to include enhancement of memory traces, with the latter appearing to depend more strongly, and in some cases exclusively, on subsequent sleep [29]. The seminal finger-tapping study by Walker and colleagues demonstrated an approximately 20% improvement in motor speed across a night of sleep without loss of accuracy, while an equivalent waking interval — with or without hand rest — provided no significant benefit, and the magnitude of overnight gain correlated robustly with the proportion of stage 2 NREM sleep [14].

Subsequent work in healthy participants has extended these findings to other motor tasks and to other modalities of practice. Debarnot and colleagues showed that subjects who imagined a sequential finger task before sleep displayed delayed performance gains comparable to those observed after physical practice, while a control group trained and retested during the daytime did not exhibit such delayed improvements [16]. The benefits of motor imagery practice on procedural memory thus appear to be at least partly sleep-dependent, in line with what has been observed after physical practice [16, 24]. Ruffino and colleagues, in a more recent study using an arm-pointing task, reported nuances in this picture: while motor imagery training produced consolidation gains across the passage of time within the same day, in their specific paradigm no significant additional gain was observed across a subsequent night of sleep, suggesting that the dynamics of sleep-dependent consolidation may differ between motor sequence learning and motor adaptation tasks [31]. These findings illustrate the complexity of offline learning processes and the importance of considering task type, training intensity and the temporal organisation of practice when interpreting sleep-related outcomes [24, 31].

Variability in the structure of practice also appears to modulate sleep-dependent consolidation [35]. Debarnot and colleagues compared constant and variable motor imagery training in a finger-tapping paradigm and reported that only the variable-practice group showed additional gains in performance after a night of sleep and exhibited the strongest transfer of skill to a novel visuomotor sequence; the constant-practice group, by contrast, showed neither further sleep-related gains nor robust transfer [35]. These results align with broader theories of motor learning that emphasise the role of contextual interference and of dorsolateral prefrontal cortex–dependent processes in the development of generalisable motor schemas, and they suggest that the way in which mental practice is structured may have non-trivial consequences for its sleep-dependent benefits [35]. Such findings have direct relevance for athletes and rehabilitation specialists who may wish to optimise the temporal and structural parameters of imagery interventions [24, 33, 35].

The proximity between training and sleep is another factor that has attracted attention. Temporiti and colleagues investigated the effect of early sleep after combined action observation and motor imagery training on manual dexterity, comparing a group that practised immediately before sleep with a group that practised at least twelve hours before sleep and a control condition [34]. Participants who practised in the "AO+MI–sleep" condition showed significantly larger improvements in manual dexterity than those in the delayed-sleep condition, with effects sustained at one-month follow-up and supported by neurophysiological correlates [34]. The authors argued that the closeness of sleep to practice may enhance the consolidation of newly acquired motor traces via offline reactivation processes during early sleep stages [34].

Although the effect sizes and the precise sleep mechanisms involved remain to be fully characterised, these findings dovetail with the broader literature suggesting that scheduling training sessions in such a way as to allow timely sleep may be a low-cost, evidence-based strategy for maximising motor learning gains in healthy and clinical populations [11, 16, 24, 34].

4.3.1. The theory of active hippocampal–neocortical dialogue

A leading mechanistic framework for understanding offline consolidation is the active system consolidation hypothesis, articulated in detail by Diekelmann and Born and extended in subsequent work [15, 30, 32]. According to this model, freshly encoded memories — initially stored in a labile form within hippocampal networks — are reactivated repeatedly during sleep and progressively transferred to neocortical sites, where they are integrated into long-term knowledge representations [15, 30]. The dialogue between hippocampus and neocortex is thought to be orchestrated by the temporal coupling of cortical slow oscillations, thalamocortical sleep spindles and hippocampal sharp-wave ripples, with the slow oscillation providing a temporal frame within which spindles and ripples nest, thereby facilitating the redistribution of memory traces from hippocampal to neocortical networks [15, 30, 33].

Behavioural and neuroimaging studies have provided convergent support for this framework. Oudiette and colleagues used a targeted memory reactivation paradigm in which sounds associated with specific learned items were replayed during slow-wave sleep, demonstrating that the cueing of low-value memories during sleep "rescued" them from forgetting and selectively strengthened the cued associations [32]. In waking, by contrast, the same auditory cues had a similar effect but appeared to be more strictly limited to the cued items, leading the authors to propose that sleep-related reactivation might both strengthen specific memories and extend benefits to categorically related items [32]. More recent work by Sifuentes Ortega and Peigneux has explored whether such reactivation processes operate differently in slow-wave and REM sleep, suggesting that cueing during distinct sleep states may engage different neural mechanisms, although the behavioural consequences for mnemonic discrimination and generalisation may be more nuanced than originally proposed [30].

In animal models, electrophysiological evidence has further illuminated the reactivation hypothesis. Spontaneous "replay" of patterns of neural activity acquired during waking has been observed in hippocampal place cells during subsequent sleep, particularly during sharp-wave ripples in slow-wave sleep, with the temporal sequence of reactivation broadly recapitulating that of waking experience [29, 32]. Although the precise generalisability of these rodent findings to human procedural memory consolidation remains debated, they are coherent with the broader view that sleep is not a passive interval of disengagement but rather an actively organised state in which memory traces are reorganised, redistributed and selectively strengthened [15, 28, 29, 32]. The framework also accommodates the observation that not all memories benefit equally from sleep consolidation; emotionally salient information, behaviourally relevant material, items associated with reward and content tagged for future use appear to be preferentially consolidated, suggesting that hippocampal reactivation operates in a selective rather than indiscriminate manner [15, 30, 32].

4.3.2. Sleep Spindles and Neural Replay

Within the active system consolidation framework, sleep spindles have been highlighted as a key electrophysiological mediator of the dialogue between hippocampus and neocortex [15, 33, 34]. These brief 0.3–2 second bursts of waxing and waning 11–16 Hz oscillations, originating in the thalamus and propagating to widespread cortical regions, occur predominantly during stage 2 NREM sleep and have been associated with the offline reactivation of newly acquired motor memories [33, 34]. Several studies have reported significant correlations between sleep spindle density or amplitude and post-sleep performance gains on motor tasks, and have suggested that spindles may provide a temporal window for synaptic plasticity within memory-related circuits [14, 29, 33].

Conessa and colleagues recently advanced the understanding of spindle-based consolidation by examining sleep spindle activity following motor sequence learning via three modalities — physical practice, motor imagery and action observation — during a daytime nap [33]. Their findings revealed a practice-unspecific temporal cluster-based organisation of sleep spindles across all modalities: spindles tended to occur in "trains" with an infra-slow rhythm of about 0.02 Hz, within which individual spindles iterated at an intermediate rhythm of about 0.2–0.3 Hz, presumably reflecting cyclic alternation between spindle bursts and refractory periods [33]. The behavioural outcomes, however, differed across modalities: a daytime nap promoted the retention of skills learned through physical practice and motor imagery, while it favoured the inter-manual transfer of skills acquired through action observation [33]. These results suggest that sleep spindle activity may serve as a general, modality-unspecific mechanism for motor memory consolidation, while the behavioural consequences of consolidation may be shaped by the modality of practice and by the resulting representations of the motor skill [33].

The role of spindles in non-physical motor learning has also been highlighted by work examining the effects of early sleep after combined action observation and motor imagery training [34]. In the study by Temporiti and colleagues, electrophysiological correlates of motor learning were detected at one-month follow-up among participants who slept shortly after training, supporting the notion that sleep — and the spindle-related processes that unfold during it — contributes to the long-term stabilisation of motor traces acquired through covert practice modalities [34]. Although the precise interaction between spindles, slow oscillations and hippocampal ripples in the human brain remains an active area of investigation, the convergence of behavioural, electrophysiological and pharmacological evidence supports a model in which sleep spindles play a central role in the offline reactivation and reinforcement of motor memories [33, 34].

Beyond their role as markers of consolidation, sleep spindles may also serve as indicators of the brain's response to specific patterns of motor learning. Erlacher and colleagues, in their trampoline study, reported changes in REM sleep parameters after a complex motor learning session, suggesting that sleep architecture may be dynamically modulated by the learning experience itself [36]. These observations are consistent with a broader pattern in which the brain appears to allocate, in a context-sensitive manner, the neural resources needed to consolidate the day's experiences, with spindles, slow oscillations and REM-related processes acting as interrelated rather than independent contributors to the consolidation process [15, 29, 33, 36].

4.4. Synaptic Tagging and Protection Against Interference

A complementary perspective on the role of sleep in motor learning emphasises its function as a protective environment in which newly acquired memory traces are shielded from interference and from the gradual decay that would otherwise occur during continued waking activity [15, 29, 32]. From this standpoint, the offline consolidation processes described above are not only about strengthening or reorganising memory traces but also about preventing the "overwriting" of these traces by new information continually being encoded during waking life [29, 32]. The notion of "synaptic tagging", borrowed from cellular neuroscience, has been invoked in this context to describe the molecular mechanisms by which recently potentiated synapses are marked for subsequent stabilisation, with sleep providing a privileged window for the relevant plasticity-related proteins to accumulate and act on tagged synapses [15].

Behavioural evidence consistent with this protective function has been reported in studies of memory selectivity during sleep. Oudiette and colleagues demonstrated that high-value associations were retained better than low-value associations across both naps and waking intervals, but that the selective rescue of low-value memories through targeted reactivation occurred more robustly when reactivation was applied during slow-wave sleep than during wakefulness, and that the entire set of low-value associations could be rescued by sleep-based reactivation, whereas waking reactivation rescued only the directly cued items [32]. The authors interpreted this dissociation as evidence that sleep entails distinctive consolidation processes that protect memories not only from passive decay but also from interference imposed by competing stimuli, and that sleep extends the benefits of reactivation to categorically related memories in a way that waking reactivation does not [32].

In the motor domain, the protective function of sleep has been documented through paradigms that introduce interfering tasks shortly after the initial learning of a motor skill. When a competing task is introduced before sleep, performance on the originally learned skill tends to be impaired, particularly in the absence of intervening sleep, suggesting that the original memory trace had not yet been sufficiently stabilised to resist interference [29]. When sleep intervenes between the original learning and the interfering task, the susceptibility to interference is markedly reduced, an effect that is consistent with a sleep-dependent stabilisation of the motor memory trace [29]. Such observations underpin practical recommendations in sport science that complex skill acquisition sessions should not be immediately followed by additional cognitively or motorically demanding activities, but rather should be followed by an opportunity for sleep — ideally a full night, but in some contexts a sufficiently long nap — so as to allow the relevant offline processes to unfold without disruption [11, 24, 34].

The protective function of sleep is also relevant to the more recent literature on motor imagery, action observation and lucid dream practice. In the work by Temporiti and colleagues, the participants who underwent action observation and motor imagery training shortly before sleep displayed larger and more durable improvements in manual dexterity than those who underwent the same training at least twelve hours before sleep, suggesting that the temporal coincidence of training and sleep may enhance the protective effects of sleep on the newly acquired motor traces [34]. Similarly, Conessa and colleagues observed that even a relatively short daytime nap was sufficient to support the consolidation and transfer of skills learned through covert practice modalities, indicating that the protective function of sleep is not confined to nocturnal sleep but extends to shorter sleep windows, provided that they include the relevant sleep stages and oscillatory events [33].

The synaptic tagging framework provides a mechanistic interpretation of these observations. According to this account, the synapses activated during the encoding of a motor skill are "tagged" by specific molecular markers that render them eligible for subsequent strengthening when plasticity-related proteins become available [15]. During sleep, particularly during slow-wave sleep, the brain enters a metabolic and neuromodulatory state that favours the synthesis and distribution of these proteins, and the orchestrated activity of slow oscillations, spindles and ripples provides a temporal scaffold for the recruitment of tagged synapses into long-term memory networks [15, 33]. Although the synaptic tagging hypothesis was originally developed at the cellular level and its precise translation to system-level motor memory consolidation remains under investigation, it offers a coherent conceptual bridge between the molecular biology of plasticity and the behavioural phenomenology of offline learning [15].

A complementary, although distinct, framework is offered by the synaptic homeostasis hypothesis, which posits that wakefulness is associated with a net potentiation of cortical synapses, while sleep — particularly slow-wave sleep — is associated with a global downscaling of synaptic strength that preserves signal-to-noise ratios and frees up metabolic and informational resources [15, 32]. From this standpoint, the apparent strengthening of specific memory traces during sleep is not the result of a generalised potentiation but rather of the selective preservation of the most strongly tagged synapses against a background of generalised downscaling, with selectivity determined by factors such as motivational salience, future relevance and prior reactivation [15, 32]. Although the synaptic homeostasis and active system consolidation hypotheses are sometimes presented as competing explanations, they may better be understood as complementary, each capturing different aspects of the multifaceted role of sleep in memory and learning [15].

Taken together, the evidence reviewed in this chapter supports the view that sleep is an active, structured process that contributes to the consolidation, reorganisation and protection of motor memory traces, with distinct sleep stages making complementary contributions through specific oscillatory and neuromodulatory mechanisms [14, 15, 29, 33]. For the athlete, this perspective implies that sleep is not merely a period of passive recovery but rather an integral component of the motor learning process, one whose preservation and optimisation may yield meaningful benefits for skill acquisition, retention and transfer [8, 9, 11, 24, 34]. It is within this conceptual framework — in which sleep is recognised as a privileged environment for the offline reprocessing of newly acquired motor memories — that the more specific question of whether deliberate motor rehearsal can be performed during sleep, and in particular during lucid REM sleep, acquires its full significance, providing the rationale for the following chapter [5, 17].

5. Lucid dreaming (LD) as an advanced training environment

5.1. The phenomenology and neurobiology of lucid dreaming: the reawakening of executive functions and the activation of the prefrontal cortex (PFC) during REM sleep

Lucid dreaming is typically defined as a dream during which the dreamer becomes aware, while remaining physiologically asleep, that the experience currently unfolding is a dream, and is often able — to varying degrees — to consciously influence its content [17, 37]. The phenomenon has been described already by classical Greek philosophers as well as by ancient Eastern contemplative traditions, but the modern scientific nomenclature can be traced to the Dutch psychiatrist Frederik van Eeden, who coined the term in 1913 and depicted lucid dreams as experiences in which "the reintegration of the psychic functions is so complete that the sleeper remembers day-life and his own condition, reaches a state of perfect awareness, and is able to direct his attention" [17, 37]. Empirical research over the past four decades has gradually transformed the topic from a relatively marginal psychological curiosity into an active area of cognitive and clinical neuroscience [17, 37, 44].

A useful conceptual map of the phenomenon was articulated by Tholey, who identified seven facets of lucidity: recognising that one is dreaming, having freedom of choice within the dream, clarity of consciousness, clarity about waking life, clarity of perception, clarity regarding the meaning of the dream and clarity of recollection [37]. While the first four are generally regarded as essential, more recent reformulations have emphasised that lucidity is best understood as existing on a continuum, with dreamers experiencing varying degrees of insight, control and access to waking-life memory rather than a strict all-or-nothing transition [37, 42]. Within this continuum, several dimensions can be partially dissociated: a dreamer may, for instance, recognise the dream state while exerting only limited control over dream content, or may exhibit strong control over the dream environment without retaining full clarity regarding waking life [17, 42].

Survey-based work has provided informative descriptive data on the phenomenology of lucid dreams. A large online survey by Stumbrys and colleagues, with 684 respondents and 571 self-identified lucid dreamers, reported that the average self-estimated duration of lucid dreams was approximately 14 minutes, although this figure should be interpreted in the context of the well-documented difficulties of estimating dream duration in retrospect [42]. Lucid dreams most often originated spontaneously, with the mean age of first occurrence reported as around 14–15 years, and lucid dreamers commonly engaged in active behaviours such as flying, conversing with dream characters and rehearsing skills, although planned actions were not always successfully recalled or executed within the dream [42]. The same survey also indicated that the frequency of lucid dream experience was the strongest predictor of phenomenological features, with frequent lucid dreamers more likely to engage in deliberate, purposeful actions within their dreams [42].

The neurobiological characterisation of lucid dreaming has advanced considerably in recent decades, although the field remains methodologically challenging due to the rarity of the phenomenon and the technical difficulties of capturing it in laboratory conditions [17, 37, 41]. Foundational neuroimaging work indicated that lucid REM sleep is associated with partial reactivation of frontal and anterior cortical regions that are typically deactivated during non-lucid REM sleep, including portions of the dorsolateral prefrontal cortex and frontopolar regions, alongside parietal areas implicated in self-reflective and metacognitive processing [17, 39]. This pattern aligns with the phenomenological observation that lucid dreaming involves a re-emergence of executive-type functions — including reasoning, intention, memory of waking-life context, and the capacity to monitor one's own state of consciousness — within an ongoing REM sleep state that, in non-lucid form, is typically characterised by reduced activity in those same prefrontal regions [5, 17, 41].

EEG-based studies have provided complementary, although sometimes mixed, evidence regarding the electrophysiological correlates of lucid REM sleep [17, 41]. Several investigations have reported elevated power in the low-beta band over parietal areas and increased gamma-band activity over frontolateral electrodes during lucid compared with non-lucid REM, although the interpretation of these findings has been complicated by issues such as the contamination of high-frequency signals by ocular muscle artefacts, particularly the saccadic spike potential [17]. Recent work using EEG microstate analysis has offered a different, network-oriented perspective. Wang and colleagues observed that microstates A and G dominated during lucid REM sleep, while microstates B, C and D were diminished, and interpreted these changes as compatible with increased self-visualisation, metacognition and executive processing alongside reduced default-mode-network-related activity [41]. Other investigators, using simultaneous resting-state functional connectivity analyses, have reported that frequent lucid dreamers display elevated functional connectivity between the anterior prefrontal cortex and temporoparietal association areas during wakefulness, overlapping with both the default-mode network and the frontoparietal control network — a pattern that may represent a trait-level correlate of the predisposition to dream lucidly [41].

The phenomenon has also been situated within broader frameworks linking sleep, contemplative practice and consciousness research. Bonamino and colleagues, in a recent review, argued that lucid dreaming, advanced meditation and other altered states share a common methodological terrain in that they offer naturally occurring, partially trainable opportunities to study graded, dynamic and minimal forms of conscious experience, in ways that complement conventional cognitive neuroscience [44]. From this perspective, lucid dreaming represents an empirically tractable example of how consciousness can persist and transform within sleep, dissociating internal awareness from the typical sensorimotor coupling that characterises waking life [17, 41, 44]. Tzioridou and colleagues, in their wide-ranging review on the clinical neuroscience of lucid dreaming, emphasised that the phenomenon is not merely an isolated curiosity but is increasingly relevant for the understanding of consciousness, dream control and body representation, and may also offer therapeutic implications for conditions such as nightmare disorder, depression and post-traumatic stress disorder [37].

Despite these advances, the literature is consistent in acknowledging that the neurobiology of lucid dreaming remains incompletely characterised [17, 37, 41]. The relatively low spontaneous frequency of lucid dreams in the general population — meta-analytic estimates suggest that approximately 53% of people have experienced at least one lucid dream in their lifetime, while around 23% can be considered regular lucid dreamers with at least one episode per month — limits the sample sizes available for laboratory research [37, 42]. Moreover, even frequent lucid dreamers often fail to achieve, or to reliably signal, lucidity in the somewhat constrained environment of a sleep laboratory, which contributes to the small participant numbers in many neuroimaging studies [17, 37, 39]. These methodological constraints should be borne in mind when interpreting the available evidence, and motivate continuing efforts to refine induction techniques, to develop more efficient laboratory protocols and to integrate findings across multiple measurement modalities [17, 37, 44].

5.2. Objective verification of the phenomenon: the use of electrooculography (EOG) and fMRI to confirm volitional control over dreaming and eye movements

For much of the twentieth century, the very existence of lucid dreaming as a distinct, physiologically grounded phenomenon was a matter of philosophical debate, with some authors maintaining that "lucid dreams" were necessarily episodes of brief hallucinatory wakefulness rather than genuine dream states [17, 38]. The decisive empirical contribution that altered this picture came from the late 1970s and early 1980s, when LaBerge and colleagues, building on prior work showing that gaze shifts within dreams could correspond to recorded eye movements of the sleeper, demonstrated that proficient lucid dreamers could be instructed to execute a predetermined sequence of voluntary eye movements upon becoming lucid, thereby providing objectively verifiable physiological signals of their conscious awareness within the dream [38]. The seminal paper by LaBerge and colleagues, published in 1981, reported five subjects who, during 35 reported lucid dreams across multiple non-consecutive nights, successfully signalled their awareness of dreaming using prearranged eye movements while polysomnographic recordings simultaneously confirmed that the signals had occurred during unequivocal REM sleep [38]. The signals — generally consisting of large horizontal saccades in a left–right–left–right pattern — were clearly distinguishable from the typical, smaller-amplitude rapid eye movements of non-lucid REM sleep, and were readily identified on the electrooculogram by judges blind to the timing of the reports [38]. In 24 of the 30 reported signals, the polysomnographic epochs were correctly identified through blind matching, with the probability of such correct identification by chance estimated as "astronomically small" [38]. This eye-signalling technique has since become the gold standard for the objective verification of lucid dreams and has been widely adopted across subsequent neuroimaging, electrophysiological and behavioural studies [17, 37, 38, 39, 40].

The methodological power of eye signalling extends beyond merely confirming the occurrence of lucid dreams. As soon as lucid dreamers can communicate to the outside world through preagreed actions, they can also be instructed to mark the beginning and end of specific in-dream tasks, thereby providing objective temporal markers for the analysis of physiological data acquired during the dream [17, 39, 40]. This capacity has transformed the previously inaccessible domain of dream content into an experimentally tractable domain in which the temporal correspondence between dream events and physiological responses can be examined directly. Subsequent work has demonstrated that bidirectional communication with lucid dreamers is, under specific conditions, also possible, with auditory or tactile cues delivered to the sleeper being responded to within the dream and the responses, in turn, signalled to the outside experimenter through preagreed eye movements or facial twitches [17, 37].

Building on the foundation provided by eye-signal verification, researchers have integrated lucid dreaming with neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (NIRS), allowing for unprecedented direct exploration of the neural correlates of dreamed actions [39]. In a key fMRI–NIRS study, Dresler and colleagues asked highly trained lucid dreamers to perform predefined hand-clenching tasks during lucid REM sleep, marking the onset and switches of the task with prearranged eye signals [39]. In the successful trials, increases in blood oxygen level-dependent (BOLD) signal were observed in the sensorimotor cortex contralateral to the indicated movement side, providing direct neuroimaging evidence that specific dreamed motor actions activate the same general cortical regions engaged during waking motor performance [39]. The BOLD signal fluctuations during dreamed hand clenching were smaller than during overt hand clenching but were of similar order to those observed during imagined hand movement in wakefulness, and the supplementary motor area showed activations of comparable amplitude across dreamed and overt movement, consistent with its role in the timing, preparation and monitoring of complex actions [39].

These findings have several methodological implications [17, 39, 41]. First, they provide direct experimental evidence that dreamed actions are not phenomenologically free-floating, but are accompanied by patterns of neural activation that resemble those observed during corresponding waking actions, thereby strengthening the analogy between motor imagery in wakefulness and motor practice in lucid dreams [3, 22, 39]. Second, they establish a methodological proof of concept that the neural correlates of specific dream contents — at least when the contents can be deliberately structured by lucid dreamers and time-locked through eye signals — can be examined using contemporary neuroimaging techniques [39]. Third, they highlight the value of lucid dreaming as a tool for the cognitive neuroscience of consciousness more broadly, as it provides a paradigm in which subjective and objective measures of conscious experience can be linked in a temporally precise manner [17, 41, 44].

The eye-signal-based verification has also been extended to other forms of physiological measurement, including the electromyographic monitoring of subthreshold limb activity during dreamed motor actions and the cardiovascular monitoring of sleeping bodies during dreamed physical exercise [40]. In a sleep-laboratory study by Erlacher and Schredl, proficient lucid dreamers were instructed to perform a structured task — counting from 21 to 25, performing 10 squats and then counting again — within lucid REM sleep, marking each phase with characteristic eye movements [40]. Cardiovascular monitoring of the sleeping bodies revealed a statistically significant increase in heart rate between the pre-exercise/exercise periods and the post-exercise period, and a non-significant but directionally consistent increase in respiratory rate during the exercise phase compared with the pre- and post-exercise phases [40]. These observations are coherent with the broader notion that the autonomic nervous system responds to dreamed motor actions in a manner that, while attenuated, mirrors the responses observed during waking exercise, supporting the view that the motor command issued during dreaming is partially "real" at the level of central and peripheral physiology [22, 39, 40].

Finally, PET-based work conducted in non-lucid REM sleep has provided complementary evidence for the experience-dependent reactivation of brain regions during sleep. Maquet and colleagues demonstrated that brain areas activated during the execution of a serial reaction time task in wakefulness — including occipital and premotor cortices — were significantly more active during subsequent REM sleep in trained subjects than in non-trained controls, in line with the hypothesis that REM sleep is a privileged window for the offline reprocessing of memory traces acquired during waking [43]. While these findings concern non-lucid rather than lucid REM sleep, they provide an important conceptual link between the broader role of REM sleep in motor memory consolidation and the more specific possibility that lucid dreamers might harness this physiological state for deliberate motor rehearsal [15, 39, 43].

5.3. The paradox of muscular atonia: how the motor cortex generates a complete descending signal for movement (producing physiological effects), while the brainstem blocks the physical execution of movement

A defining feature of REM sleep, common to both lucid and non-lucid episodes, is the near-complete loss of skeletal muscle tone known as REM-atonia, generated by descending inhibitory signals from brainstem structures, particularly within the pontomedullary network [39, 40]. This atonia serves an evident behavioural function: it prevents the overt enactment of dream content, thereby protecting the dreamer (and any nearby individuals) from injury during emotionally and motorically active dreams [40]. Pathologies in which this inhibitory mechanism fails — most notably REM sleep behaviour disorder — provide indirect support for the central role of brainstem-generated atonia, as patients with this condition may overtly enact dream fragments, sometimes with dramatic and dangerous consequences [39].

The combination of relatively preserved cortical activation and near-total inhibition of peripheral motor output generates what may be characterised as the paradox of muscular atonia [22, 39, 40]. On the one hand, the motor cortex, premotor cortex, supplementary motor area and associated circuits are clearly engaged during dreamed motor activity, generating descending signals that resemble — although in attenuated form — those issued during waking motor execution [22, 39]. On the other hand, this descending command does not result in overt motion at the level of skeletal muscles, because brainstem inhibition prevents the relevant motor neuron pools from being effectively driven [39, 40]. The result is a state in which the motor system is functionally "active" at higher levels of the neuraxis while being functionally "blocked" at the spinal cord and peripheral effectors, allowing the brain to simulate movement without producing it.

The neuroimaging study by Dresler and colleagues provides direct empirical support for this paradoxical pattern [39]. Their fMRI data show that dreamed hand clenching during lucid REM sleep elicits activation in the sensorimotor cortex contralateral to the indicated movement side, with BOLD signal fluctuations of approximately 1.8–2.5% — substantially smaller than the 4.5–5.6% fluctuations observed during executed hand clenching in wakefulness, but of similar magnitude to those observed during imagined hand movement in wakefulness [39]. The supplementary motor area showed amplitudes similar to those of overt hand clenching, suggesting that the higher-level planning and timing of the action are largely preserved even in the absence of overt motor output [39]. The authors interpreted these findings as supportive of the view that the inhibition of motor output during motor imagery and during dreamed movement reflects a "blocking mechanism downstream of the motor cortex" rather than a high-level prefrontal blockade, with REM atonia and corticospinal inhibition combining to prevent overt motion [39].

Complementary electromyographic evidence supports this interpretation. While REM-atonia largely abolishes voluntary muscle activity, small phasic twitches can be detected on EMG recordings of limbs corresponding to dreamed movements, suggesting that the descending motor command partially "leaks" through the brainstem inhibition without producing visible motion [39, 40]. EMG bursts in the forearm during dreamed fist clenching, for instance, have been described in eye-signal-verified lucid dreams, and have been interpreted as residual peripheral correlates of the dreamed motor command [39]. These twitches are not sufficient to produce functional motion but provide a window onto the partially preserved corticospinal output during dreamed action [39].

At the autonomic level, the consequences of this paradoxical configuration are particularly intriguing. As discussed above, dreamed physical exercise — for instance, performing squats during a lucid REM dream — has been associated with measurable increases in heart rate and trends towards increased respiratory rate in the sleeping body, even in the complete absence of overt motor activity [40]. From the perspective of the cardiovascular and respiratory systems, dreamed exercise is treated as a partially "real" event, with anticipatory adjustments in autonomic outflow consistent with those typically observed during waking exercise of comparable intensity [40]. These findings extend, into the dreaming state, the well-established literature on the autonomic correlates of motor imagery in wakefulness, suggesting that central command signals generated during dreamed motor activity are sufficient to trigger autonomic adjustments even though peripheral motor output is suppressed [3, 19, 22, 40].

The paradox of muscular atonia is highly relevant for the conceptual framing of lucid dream practice as a potential training modality [5, 7, 39, 40]. From this perspective, the lucid dream state offers a unique configuration in which the brain may engage in deliberate, structured motor rehearsal — complete with prefrontal executive engagement, sensorimotor activation, autonomic adjustments and partial corticospinal output — without the metabolic demands and injury risk associated with overt motion. The motor commands are "real" in the sense that they engage the same general circuits as overt action, but they are "harmless" in the sense that they do not result in actual muscle contraction; the result is a state that has been compared, in some narrative reviews, to a high-fidelity, brain-internal virtual reality with full kinesthetic and proprioceptive immersion [5, 39, 40].

This configuration also helps to explain why the literature has emphasised lucid REM sleep, rather than non-lucid dreaming, as the principal candidate state for deliberate motor practice during sleep [5, 6, 7, 17]. Non-lucid dreams, by their very nature, are not amenable to deliberate, goal-directed rehearsal: dreamers typically lack insight into the dream state and cannot intentionally structure their actions in accordance with prearranged training plans. Lucid REM sleep, by contrast, combines the executive and metacognitive functions characteristic of wakefulness with the sensorimotor immersion and physiological isolation of REM sleep, providing the conditions under which deliberate motor rehearsal can plausibly take place [5, 17, 39, 41]. The neurobiological signature of lucid REM sleep — partial prefrontal reactivation, preserved sensorimotor activation, persistent REM-atonia and autonomic responsiveness to dreamed action — constitutes the substrate upon which the empirical literature on lucid dream practice has been built [17, 39, 40].

From a methodological standpoint, the paradox of muscular atonia also offers important practical advantages for sleep-laboratory research [38, 39, 40]. Because peripheral motor output is suppressed, neuroimaging and polysomnographic measurements can be obtained during dreamed motor activity without the artefacts that would be produced by overt motion. Eye signals, although themselves motor in nature, are preserved during REM sleep because the extraocular muscles are less affected by REM-atonia, and can therefore serve as reliable temporal markers for the synchronisation of physiological recordings with dream events [38, 39]. The combination of preserved cortical engagement, suppressed peripheral motor output and accessible ocular signalling thus creates an unusually favourable methodological situation, in which the inner motor activity of the dreamer can be inferred and timed with a precision that is rarely achievable in studies of conventional motor behaviour [17, 39].

Taken together, the evidence reviewed in this chapter supports the view that lucid REM sleep represents a distinctive state of consciousness in which several features classically associated with wakefulness — including metacognitive insight, volitional control, and partial prefrontal engagement — coexist with the sensorimotor immersion and physiological characteristics of REM sleep [17, 39, 41, 44]. Within this state, dreamers can deliberately rehearse motor skills under conditions of preserved cortical and autonomic engagement and full corticospinal inhibition, in what may be described as a high-fidelity internal simulation environment [5, 39, 40]. The behavioural consequences of such rehearsal for subsequent waking performance, and the conditions under which these consequences are more or less robust, will be examined in detail in the following chapter, which considers the empirical literature on lucid dream practice in athletes and on its comparison with physical and mental practice in wakefulness [5, 6, 7].

6. Lucid dream practice (LDP) and athletic performance

6.1. The effectiveness of LDP relative to classical training: A comparison of physical practice, waking mental practice (MP) and lucid dream practice

Lucid dream practice (LDP) refers to the deliberate rehearsal of motor skills within a lucid dream, conducted with the intention of improving subsequent waking performance [5, 6, 7]. Conceptually, it can be considered a specific subcategory of mental practice, in that it involves the cognitive rehearsal of a motor task in the absence of overt physical movement; phenomenologically and physiologically, however, it differs from waking mental practice in several non-trivial respects, most notably in being embedded within an immersive, internally generated dream environment during REM sleep [5, 7, 45]. The hypothesis that motor rehearsal within lucid dreams may transfer to waking performance can be traced back to early qualitative work by Tholey, who reported that experienced lucid dreamers were able to perform and practice complex sport skills, including skiing and gymnastics elements, within their dreams, with subjective improvements in subsequent waking performance [5, 7, 48].

A first quantitative test of this hypothesis was provided by Erlacher and Schredl, who conducted a pilot field experiment with a pre–post design involving a simple coin-tossing task [5, 6, 48]. Twenty participants attempted to practice the task in a lucid dream on a single night, and seven of them succeeded; their performance was compared with that of a physical practice group and a no-practice control group. Both the lucid dream practice and physical practice groups showed significant increases in hitting the target from pretest to posttest, while no significant increase was observed in the control group [6, 48]. Although the improvements following lucid dream practice were somewhat smaller than those after physical practice, the differences between the two practice groups did not reach statistical significance, providing tentative early evidence that motor rehearsal in lucid dreams can produce measurable performance gains [6].

A second, more directly comparative test was conducted by Stumbrys and colleagues, who used a sequential finger-tapping task — a well-established paradigm for studying procedural motor learning — and compared the effectiveness of LDP not only to actual physical practice (PP) but also to waking mental practice (MP) [6]. Sixty-eight participants completed an online experiment in which they were assigned to four groups: LDP (n = 17, recruited from frequent lucid dreamers), MP (n = 15), PP (n = 16) or no-practice control (n = 16) [6]. The pretest took place in the evening and the posttest in the morning, with the practice (or absence thereof) conducted during the night [6]. All three practice groups significantly improved their performance from pretest to posttest, while no significant improvement was observed in the control group; subjective sleep quality was not affected by night practice [6]. The effects of LDP appeared to be broadly similar in magnitude to those of PP and MP in wakefulness, although the limited sample sizes and the field-experiment nature of the study warrant caution in the interpretation of effect sizes [6].

A third quantitative study, conducted by Schädlich and colleagues, brought lucid dream practice into a sleep laboratory setting and used a dart-throwing task with polysomnographic verification of lucidity through eye signals [45]. Out of 15 lucid dreamers participating in the study, nine succeeded in practising darts within a lucid dream; their performance was compared with that of a physical practice group (n = 9) and a no-practice control group (n = 9) [45]. A significant interaction effect ($P = 0.013$, $\eta^2 = 0.368$) was reported, and a closer examination of the lucid dream practice group — divided post hoc into participants with few (n = 4) versus many (n = 5) distractions during the dream — revealed that only the lucid dreamers with few distractions improved significantly over time, with an 18% improvement and a very large within-group effect size ($P = 0.005$, $d = 3.84$) [45]. The lucid dreamers with many distractions did not show significant improvement, suggesting that the efficacy of lucid dream practice may depend strongly on the dreamer's ability to maintain focused, structured rehearsal within the dream [45]. These findings are consistent with the broader theoretical framework on motor imagery, according to which attentional focus and contextual realism are among the principal modulators of mental practice efficacy [3, 24].

Survey-based studies provide additional, more naturalistic evidence regarding the use and perceived effectiveness of lucid dream practice in athletes. In a questionnaire study of 840 German athletes, 57% reported having experienced at least one lucid dream in their lifetime, and 24% reported lucid dreams at least once a month; of the lucid dreamers, 9% reported using lucid dreams to practice sport skills, and about 77% of those who did had the impression that their waking performance had improved as a result [6, 48, 49]. A parallel study in 1,323 Japanese college athletes used the same questionnaire translated into Japanese and reported that approximately 41% had experienced at least one lucid dream, 18% experienced lucid dreams once a month or more, and around 3.6% of the total sample used lucid dreams for sport practice [48]. While the absolute frequencies differed between the German and Japanese samples, the proportion of lucid dreamers who used lucid dreams for sport practice and the perceived improvements in waking performance were broadly comparable, suggesting that lucid dream practice may have a cross-cultural applicability, although cultural and methodological factors may influence the prevalence of the phenomenon itself [48, 49].

A qualitative study by Schädlich and Erlacher complements these quantitative findings [7]. Sixteen lucid dreamers, recruited from several countries and active in a variety of sports — including martial arts, skiing, gymnastics, climbing, parkour, swimming, dance and snowboarding — were interviewed in depth about their use of lucid dream practice [7]. Thirteen of the sixteen interviewees (81.3%) reported positive effects of LDP, with ten participants reporting improvements in physical performance, while others described strengthened confidence, insights for waking physical practice, improved flexibility and positive emotional outcomes [7]. The same study highlighted that LDP afforded special possibilities not easily available in waking practice, such as the deliberate manipulation of practice conditions, the alteration of perceived gravity or speed, and the practice of movements that would be technically impossible or unsafe in waking life [7]. Although these qualitative observations cannot, on their own, establish the efficacy of LDP, they enrich the quantitative picture by illustrating the phenomenological texture of in-dream rehearsal and the perceived advantages and limitations reported by athletes themselves [5, 7].

A recent online survey of adolescent athletes and non-athletes by Bonamino and colleagues extended these findings to younger populations [51]. Lucid dreams were prominent among adolescents (67.4% experienced lucid dreams at least once, 30.0% at least once a month and 12.9% at least once a week), with no marked difference in frequency or uses between athletes and non-athletes [51]. Among adolescents who reported practising sports or dance in lucid dreams, a higher proportion (57.1%) reported improvements in waking self-efficacy than improvements in actual sport performance (42.9%), suggesting that the perceived benefits of LDP may extend beyond technical skill enhancement to psychological dimensions such as confidence, motivation and self-belief [51]. A more general online survey on the applications of lucid dreams reported by Schädlich and Erlacher provided further descriptive data, with 21.3% of 301 lucid dreamers indicating that they used lucid dreams to "practice a particular movement to improve skills in daily life", a frequency comparable to those reported for problem-solving (29.9%) and creative ideas (27.6%) [52]. These figures are consistent with the broader picture in which motor practice represents a meaningful, although not dominant, application of lucid dreams within the general population of lucid dreamers [42, 52].

Taken together, the quantitative, qualitative and survey-based evidence converges on a relatively cautious conclusion: lucid dream practice appears to produce measurable improvements in subsequent waking performance, at least for certain motor tasks and under favourable conditions, with effects that may be comparable in magnitude to those of waking mental practice and possibly smaller than those of full physical practice [5, 6, 45]. However, the efficacy of LDP appears to be conditional on factors such as the dreamer's level of control over the dream, the stability of the dream environment, the avoidance of distractions and the appropriate selection of the task to be rehearsed [7, 45, 47]. The next sections of this chapter examine in greater detail two of these conditioning factors — the immersive, first-person three-dimensional nature of the dream environment and the role of intra-dream attention and distraction in determining whether the in-dream practice transfers to waking performance.

6.2. First-person perspective and the 3D dream environment: why the dream environment (full kinesthesia, immersion, dream gravity) may be more powerful than waking imagery

A recurring theme in the lucid dream practice literature is the proposition that the dream environment, by virtue of its fully immersive, multisensory, first-person character, may provide an unusually rich substrate for motor rehearsal — potentially more closely approximating actual physical practice than is feasible with waking motor imagery alone [5, 7, 47]. Peters and colleagues, in a recent theoretical contribution, articulated this idea by describing lucid dreaming as offering a "VR-like" environment in which the dreamer's body, the action, the environment, the equipment and even the presence of dream characters can be shaped to render the simulation as close to reality as possible [5]. From this perspective, lucid dream practice extends the construct of mental practice in two important ways: it preserves the cortical activation patterns associated with imagery, while embedding them within a sensorially immersive context that simulates the proprioceptive, visual, auditory and emotional features of the corresponding waking performance [5, 7].

Several lines of evidence support this view. Neuroimaging work using fMRI and NIRS during lucid REM sleep has shown that dreamed motor actions activate the sensorimotor cortex and the supplementary motor area in a manner that, while attenuated relative to overt motor execution, is of comparable order to that observed during waking motor imagery [39]. In some cases — for instance, in the supplementary motor area — activation amplitudes during dreamed motor tasks may approach those observed during overt motor execution, suggesting that the planning and timing of the action may be processed with a fidelity that is closer to actual performance than to imagined performance in wakefulness [39]. Cardiovascular and electromyographic studies further indicate that dreamed physical exercise can elicit autonomic responses — including increases in heart rate and respiratory rate — and partial corticospinal output, in line with the notion that the motor command issued during lucid dream practice engages both central and peripheral physiological systems to a non-trivial degree [40].

The qualitative evidence from athletes provides a complementary, phenomenological perspective on the immersive nature of the dream environment [7]. In the interviews conducted by Schädlich and Erlacher, participants frequently described their lucid dream practice experiences as very realistic, including the perception of kinesthetic sensations, of the resistance of equipment, of the texture of surfaces and of the presence of partners or opponents [7]. The athletes also reported that required equipment or sparring partners were usually available in the dream environment, or could be created and adjusted at will — a feature with no direct analogue in waking life [7]. Some athletes used the malleability of the dream environment to deliberately manipulate the conditions of practice, slowing down the speed of execution to focus on technical details, altering the apparent force of gravity to facilitate or complicate the practice, or rehearsing movements that they could not yet perform in waking life [7]. A springboard diver, for instance, reportedly practised complex twists and somersaults by mentally decelerating the entire sequence, while a snowboarder used the dream environment to rehearse tricks beyond his current waking proficiency [7, 48].

This dimension of dream control — the capacity to actively shape the dream environment and the parameters of practice — has been highlighted as one of the principal theoretical advantages of LDP over waking mental practice [5, 7, 47]. Peters and colleagues, in a recent case study examining juggling as a complex lucid dream motor task, articulated this in terms of an interplay between "bottom-up" sensorimotor processes that support successful motor execution and "top-down" regulatory processes that allow the dreamer to manipulate dream content [47].

The authors noted that, although awareness of dreaming (lucidity) is the prerequisite for any deliberate practice, awareness alone does not guarantee the capacity to alter the dream world, and that dream control varies considerably between and within individuals [47]. In their study of four participants attempting to juggle within lucid dreams, both dream control and self-efficacy appeared to predict the ability to execute the task, with one participant succeeding in the task across multiple nights and others struggling with dream instability, scenery changes or premature awakening [47].

A further potential advantage of LDP is the absence of physical fatigue and the elimination of injury risk during practice [5, 7, 47]. Because lucid dream practice takes place under conditions of REM-atonia, the dreamer's body remains physically at rest, with cardiovascular and respiratory adjustments occurring at a level that, while greater than baseline sleep, remains far below those produced by overt exertion [40]. This combination of immersive cognitive engagement and physical rest opens up potentially valuable applications for athletes recovering from injury, for those undergoing tapering periods before competition, or for those whose waking training schedules are constrained by environmental or logistical factors [5, 7, 51]. At the same time, several authors have noted that the very richness and malleability of the dream environment can paradoxically interfere with structured practice if not appropriately managed [7, 47]. Dream scenes may shift abruptly, dream characters may interfere with the planned activity, perceived gravity or the physics of the dreamed body may behave in unpredictable ways, and the dreamer may struggle to maintain stable contact with the practice task [7, 45, 47]. A specific aspect of the dream environment that has received particular attention is the temporal organisation of dreamed motor actions [50]. Erlacher and colleagues examined the time required to perform counting, walking and gymnastic routines in lucid dreams compared with wakefulness, and found that motor tasks consistently took longer in lucid dreams than in waking life — by approximately 40–50% for walking, 40% for squats and 23% for a more complex gymnastic routine — while the time required for purely cognitive tasks such as counting was approximately equivalent across states [5, 50]. These differences have been interpreted as reflecting the lack of muscular feedback due to REM-atonia and the slower neural processing during REM sleep, although task length did not appear to disproportionately affect dream time, with relative durations preserved across walking sequences of 10, 20 or 30 steps [50]. From a practical standpoint, these findings imply that practitioners of LDP should not expect a perfect one-to-one correspondence between in-dream time and waking-life time for motor actions, although the temporal proportions of complex sequences appear to be largely preserved [50].

Despite these caveats, the available evidence is broadly consistent with the proposition that lucid dream practice offers a uniquely immersive form of mental practice, with first-person sensorimotor engagement, environmental malleability and freedom from physical fatigue and injury risk [5, 7, 39, 47]. Whether and to what extent these properties translate into superior or simply complementary effects on waking performance, relative to waking mental practice, remains an open empirical question. The available evidence suggests that, in some cases, LDP may produce effects comparable to those of MP and possibly closer to those of PP, although the methodological constraints of the existing literature — small sample sizes, heterogeneous tasks, and the rarity of laboratory-controlled trials — preclude firm conclusions [6, 7, 45]. As the next section will detail, the efficacy of LDP also appears to depend critically on the dreamer's capacity to manage the attentional and contextual challenges of the dream environment, and in particular on the avoidance or minimisation of intra-dream distractions [45, 47].

6.3. The role of distractors: the role of focused attention within the dream (Schädlich's studies) — how intra-dream distractions undermine the transfer of motor skills to waking life

While the dream environment offers important advantages for motor rehearsal, it also presents distinctive challenges that may compromise the efficacy of lucid dream practice [7, 45, 47]. Foremost among these is the issue of intra-dream distraction: the tendency of dream characters, environmental events, scene changes or fluctuations in lucidity to interfere with the structured rehearsal of motor skills [45, 47]. The empirical importance of this factor was highlighted by Schädlich and colleagues in their sleep-laboratory pilot study of dart throwing, in which the lucid dream practice group was post hoc divided into participants who experienced few versus many distractions during the dream [45]. Only the lucid dreamers with few distractions showed significant improvement in dart-throwing accuracy, while those with many distractions failed to improve, despite having achieved lucidity and having attempted the task [45].

The qualitative descriptions of intra-dream distractions reported in the dart-throwing study illustrate the heterogeneity of these phenomena [45, 47]. One participant, for instance, described being repeatedly interrupted by a dream character: "The doll kept throwing darts at me", while another reported the gradual destabilisation of the dream environment: "I noticed it was getting somewhat unstable… I managed three or four more throws and then I woke up" [47]. These accounts converge on a recurring picture in which the dreamer's ability to remain focused on a structured rehearsal task is constrained by the relative instability of the dream environment, the unpredictability of dream content and the fluctuations of lucidity itself, which often exists on a continuum rather than as a stable, all-or-nothing state [37, 47]. The implication is that the achievement of lucidity is a necessary but not sufficient condition for effective LDP; the dreamer must additionally maintain focused attention, environmental stability and procedural fidelity for the duration of the rehearsal [45, 47].

The four case reports of lucid dream juggling reported by Peters and colleagues extend these observations to a more complex motor task [47]. Juggling was selected by the authors precisely because it requires not only procedural motor coordination but also volitional dream control, dream stabilisation, object manipulation and the regulation of dream physics (such as the perceived gravity acting upon the juggling balls) [47]. The four participants varied considerably in their capacity to perform the task within the dream, with two providing detailed case reports of lucid juggling attempts and others struggling with elements such as object stability or sustained attention [47]. Both dream control and self-efficacy appeared to predict performance, suggesting that individual traits relevant to attentional regulation and confidence may shape the extent to which a dreamer can maintain structured rehearsal of a complex motor task within a lucid dream [47]. Although the small sample limits the strength of the conclusions, the study provides empirical scaffolding for the more general claim that the effectiveness of LDP depends substantially on the dreamer's intra-dream attentional and regulatory skills [47].

From a theoretical standpoint, these findings can be situated within broader work on the cognitive determinants of motor imagery efficacy [3, 22, 24]. Comprehensive reviews of motor imagery practice have repeatedly identified attentional focus, contextual realism and the absence of distracting stimuli as moderators of training-induced effects on motor performance [3, 22, 24]. In waking life, mental practice protocols typically include explicit instructions to perform the rehearsal in a quiet environment, in a controlled posture and with attention directed exclusively to the relevant features of the simulated action [3, 22]. The reduced efficacy of LDP under conditions of intra-dream distraction can be regarded as the analogue, within the dream state, of this well-established attentional sensitivity of motor imagery in wakefulness [22, 45, 47].

A further conceptual contribution comes from work on dream control as a learnable skill [37, 47]. Several authors have proposed that dream control varies along a continuum that is partially independent of lucidity per se, and that some lucid dreamers retain only minimal control over dream content despite being fully aware of dreaming [37, 47]. Within the lucid dream practice literature, this distinction has been used to explain inter-individual variability in performance outcomes following LDP: dreamers with high lucidity and high dream control tend to engage in more structured, distraction-free rehearsal and thereby derive greater benefit from LDP, while dreamers with high lucidity but low control may struggle to maintain a stable practice routine despite their awareness [45, 47]. Peters and colleagues argue that this distinction has practical implications for the application of LDP in athletic and clinical contexts, since interventions aimed at enhancing dream control — for instance, through self-efficacy training, structured pre-sleep visualisation or specific dream stabilisation techniques — may be at least as important as those aimed at increasing the frequency of lucid dreams themselves [47].

The role of self-efficacy emerges as a particularly relevant individual difference variable in this context [47, 51]. In the juggling case reports, both dream control and self-efficacy appeared to predict participants' ability to execute the task, suggesting that the dreamer's confidence in their capacity to perform may contribute to the realism and stability of the dreamed action [47]. In the online survey of adolescent athletes, the proportion reporting improvements in waking self-efficacy after sport-related LDP exceeded the proportion reporting improvements in sport performance per se, raising the possibility that LDP may exert part of its effects via psychological mechanisms — including increased confidence, motivation and self-belief — in addition to, or alongside, direct motor learning effects [51]. Although these inferences should be interpreted cautiously given the descriptive nature of the data, they are consistent with the broader sport psychology literature on the role of self-efficacy in performance and on the multidimensional outcomes of mental training interventions [1, 2, 24, 51].

Methodological challenges in the empirical study of intra-dream distraction should also be acknowledged [37, 45]. Distractions can take many forms — environmental destabilisation, dream character interference, intrusion of unrelated dream content, fluctuations of lucidity, premature awakening — and their identification typically depends on retrospective dream reports of variable detail and reliability [45, 47]. The development of more standardised qualitative coding schemes for in-dream behaviour, the integration of polysomnographic markers with structured dream interviews and the use of repeated within-subject designs may help to refine the characterisation of intra-dream distraction in future work [37, 45, 47]. Importantly, several authors have suggested that intra-dream distraction may itself be amenable to training, with regular practice of meditation, dream control exercises and pre-sleep intention-setting being among the strategies that have been proposed to enhance focus within the dream state [17, 37, 47].

In summary, the available evidence indicates that lucid dream practice can produce measurable improvements in waking motor performance under appropriate conditions, but that the magnitude of these effects is conditional on the maintenance of focused attention within the dream, on the dreamer's capacity to manage the dream environment and on individual differences in dream control and self-efficacy [6, 7, 45, 47]. Distractions — whether in the form of dream characters, scene changes, scenery shifts or lucidity fluctuations — appear to substantially diminish the transfer of in-dream rehearsal to waking performance [45, 47]. From an applied standpoint, this implies that the effective use of LDP in athletic preparation may require not only the induction of lucid dreams but also the cultivation of the dreamer's capacity to remain attentionally engaged within the dream — a skill that, like motor imagery itself, may be learnable but requires consistent practice and individualised support [37, 47]. The following chapter will turn from these empirical and theoretical considerations to the practical question of how lucid dream practice might be integrated into the work of coaching staff, sport psychologists and rehabilitation teams, taking into account the available induction techniques, the limitations and risks of the approach and its potential place within the structured organisation of a competitive macrocycle [5, 17, 51].

7. Practical applications, barriers and methodology for coaching Staff

7.1. Induction of lucid dreams: an overview of safe and reliable techniques for entering lucid sleep relevant to athletes (e.g. MILD, WBTB, reality testing)

Although lucid dreams may occur spontaneously, the practical use of lucid dream practice (LDP) in an athletic context generally presupposes that athletes can, at least to some extent, reliably induce or increase the frequency of their lucid dreams [17, 53]. A systematic review by Stumbrys and colleagues, identifying 35 studies on lucid dream induction (11 sleep-laboratory and 24 field studies), concluded that lucid dreaming is a learnable ability and that a variety of cognitive, external and pharmacological techniques have been proposed; however, none of the techniques reviewed has been shown to induce lucid dreams reliably and consistently across all participants, and the overall methodological quality of the underlying studies was relatively modest [53]. A pragmatic implication of this assessment is that any introduction of LDP into a training programme should be framed cautiously, with realistic expectations regarding the frequency of induced lucid dreams and individualised expectations regarding outcomes [17, 47, 53].

Within the cognitive family of induction techniques, the Mnemonic Induction of Lucid Dreams (MILD) developed by LaBerge is among the most widely cited and methodologically studied [17, 53]. MILD relies on the principle of prospective memory: before going to sleep (or, more typically, during a brief awakening from REM sleep), the practitioner repeatedly forms the intention to remember that they are dreaming next time they dream, often combined with the deliberate visualisation of a recent dream and the rehearsal of recognising it as a dream [17, 53]. Several laboratory and field studies have reported that MILD can increase lucid dream frequency, although the absolute success rates remain modest and depend on factors such as dream recall, sleep timing and the dreamer's pre-existing experience [17, 53]. From the standpoint of an athlete or coaching staff, MILD has the practical advantage of requiring no equipment beyond a quiet pre-sleep ritual and a structured intention-setting routine, which may be readily integrated into existing bedtime habits [5, 53].

A second commonly described technique is Wake-Back-To-Bed (WBTB), often used as a stand-alone strategy or in combination with MILD [17, 53]. In its basic form, WBTB requires the practitioner to set an alarm for the late portion of the night — typically four to six hours after sleep onset — to remain awake for a brief period (commonly 20 to 60 minutes) engaging in mild cognitive activity related to lucid dreaming, and then to return to sleep with the intention of becoming lucid in subsequent REM episodes [17, 53]. The rationale rests on the increased proportion of REM sleep observed in the late portion of the night and on the heightened cortical activation accompanying the post-awakening return to sleep, which may facilitate the achievement of metacognitive awareness within the subsequent dream [17, 53]. Empirical work suggests that WBTB and its combination with MILD can yield higher rates of lucid dreaming than either technique alone, although at the cost of some sleep fragmentation, an issue that will be considered in detail in section 7.2 [17, 51, 53].

Reality testing constitutes a further cognitive technique, in which practitioners cultivate the habit, during waking life, of repeatedly questioning whether they are dreaming or awake, often by checking specific perceptual or cognitive features (for instance, looking at one's hands, attempting to read a piece of text twice in succession, or pressing one finger against the opposite palm) [17, 47, 53]. The underlying assumption is that the habitual performance of such checks during the day will, with sufficient repetition, "leak" into the dream state and trigger lucidity once the dreamer notices a discrepancy [17, 53]. Although individual studies report modest effects, reality testing is generally regarded as a low-burden, low-risk practice that may be useful as part of a broader induction programme rather than as a stand-alone technique [17, 53]. Variants of this approach include intention-setting, autosuggestion and Tholey's combined technique, the last of which integrates several cognitive elements (reality testing, intention, autosuggestion) into a structured daily and nightly practice [37, 53].

External and technological induction methods constitute a second broad family of techniques [17, 53]. These include the application of sensory stimuli — light flashes, auditory cues, vibrations or mild electrical stimulation — during REM sleep, with the aim of being incorporated into the dream and triggering the dreamer's recognition of the dreaming state [17, 39, 41, 53]. Although several devices have been developed and marketed, the empirical literature suggests that the reliability of these methods remains limited and that they may produce, at best, an enhancement of lucidity rather than a guaranteed induction [17, 53]. Pharmacological strategies, including the use of cholinergic agents, have also been investigated in laboratory settings, but their applicability to athletes is constrained by safety, ethical and anti-doping considerations and is therefore generally not recommended within the framework of contemporary sport science [17, 53]. For the purposes of an athletic context, cognitive techniques — MILD, WBTB, reality testing and their combinations — represent the more practical and safer family of options [5, 47, 53].

The selection of induction techniques for an individual athlete should take into account the athlete's baseline lucid dream frequency, sleep schedule, training load and personal preferences [7, 11, 53, 56]. Survey data indicate that lucid dreaming is comparatively prevalent among athletic populations, with 57% of German athletes and approximately 41% of Japanese college athletes reporting at least one lucid dream in their lifetime, and substantial proportions (24% and 18% respectively) experiencing lucid dreams at least once a month [48, 49]. Among adolescent athletes and non-athletes, 67.4% reported at least one lucid dream, with 30.0% experiencing them at least once a month [51]. These figures suggest that a sizeable proportion of athletes already possess some degree of natural predisposition to lucid dreaming, which may simplify the introduction of structured induction protocols for those who wish to use LDP as part of their preparation [48, 49, 51].

It is also important to emphasise that the induction of lucid dreams should not be conceived merely as a means of increasing frequency: as discussed in Chapter 6, the efficacy of LDP depends not only on the achievement of lucidity but also on the dreamer's capacity for intra-dream attentional control, dream stability and structured rehearsal [45, 47]. Several authors have therefore advocated a holistic approach that combines induction techniques with the deliberate cultivation of dream control skills, including pre-sleep visualisation of the intended in-dream task, self-suggestion regarding the maintenance of focus and the practice of dream stabilisation techniques such as spinning, hand rubbing or sensory grounding within the dream [7, 47, 56]. From the standpoint of a coaching staff, this implies that the introduction of LDP should be accompanied by parallel work on imagery vividness, attention regulation and mental representation of the target skill, in line with the well-established literature on motor imagery practice in wakefulness [3, 22, 24, 26].

Practical guidance for the integration of induction techniques into athletes' routines must also take into account the variability of individual response and the time required to develop proficiency [7, 47, 56]. Although some athletes may experience lucid dreams within days or weeks of beginning structured practice, others may require months of consistent effort, and a minority may remain unable to achieve lucidity reliably under sleep-laboratory or training-camp conditions [37, 47, 53]. This variability has clear implications for expectations: lucid dream practice should not be promoted as a guaranteed shortcut to performance enhancement but rather as a potentially useful adjunct whose benefits, where they occur, accumulate over time and depend on the broader sleep, training and psychological context of the athlete [5, 7, 53]. A recent qualitative case study by Ableidinger and Holzinger, based on a detailed interview with a martial-arts practitioner who used lucid dreams to explore movement and creativity, illustrates the personalised and exploratory character of LDP as it is actually practised by athletes outside controlled laboratory settings, and reinforces the importance of patient, individualised guidance from a knowledgeable mentor or sport psychologist [56].

7.2. Limitations and risks: methodological difficulties, sleep hygiene, the risk of sleep fragmentation under inappropriate use of induction techniques (including sleep paralysis and false awakenings)

The applied use of lucid dream practice in elite sport is not without its limitations and risks, which should be carefully considered before any structured implementation [11, 51, 53]. The first and most fundamental constraint is methodological: as discussed in earlier chapters, the empirical literature on LDP remains relatively small, with only a handful of laboratory-controlled studies, modest sample sizes, heterogeneous tasks and a paucity of investigations in elite athletic populations [5, 6, 7, 45]. Although the available evidence is broadly consistent with a modest positive effect of LDP on subsequent waking performance, the overall body of work has been described in meta-analytical terms as suggesting a medium positive effect size that, in the most recent appraisals, did not reach statistical significance, partly because of the small number of studies and the wide confidence intervals [56]. From an evidence-based standpoint, this implies that LDP should be presented to athletes and coaches as a promising but still tentative modality, the use of which should be embedded within broader, more thoroughly validated training and recovery strategies [5, 7, 56].

A second category of limitations concerns the impact of induction techniques on sleep architecture and sleep hygiene [11, 17, 51]. Several induction methods, most notably WBTB, require deliberate interruption of nocturnal sleep, with practitioners awakening in the early morning hours and remaining awake for a period before returning to sleep [17, 53]. While this fragmentation may be tolerable for non-athletic adults in occasional use, it raises specific concerns in the context of elite sport, where adequate sleep is increasingly recognised as a cornerstone of recovery and performance, and where chronic or even acute sleep restriction has been associated with impaired reaction time, cognitive functioning, neuromuscular control and injury risk [8, 9, 10, 11]. The literature has therefore cautioned against the indiscriminate use of WBTB and similar methods in high-load training periods or immediately before competitions, and has recommended that induction protocols be scheduled to minimise interference with the overall sleep budget [11, 51].

Empirical work on sleep disorders in elite athletic populations adds further nuance to these considerations. A large-scale Swiss survey of 2,293 elite athletes by Vorster and colleagues reported that approximately one in four athletes exhibited symptoms suggestive of clinically relevant sleep disorders, including insomnia (7.5%), sleep apnoea (3.4%), restless legs syndrome (6.6%), nightmares (6.3%) and non-REM parasomnias such as sleepwalking and night terrors (8.7%); 18.3% perceived their sleep as non-restorative, 20.1% showed poor sleep efficiency, and 17.7% demonstrated poor sleep health overall [55]. The authors emphasise that sleep disorders may impair athletic performance and increase the risk of mental-health problems, particularly depression and anxiety, and recommend routine screening and treatment as part of comprehensive athlete care [55]. Against this background, the introduction of any practice that may further fragment sleep should be undertaken with particular caution, and only after baseline sleep health has been assessed and any underlying sleep disorders have been appropriately managed [11, 55].

Beyond the macroscopic concern of total sleep duration, several specific phenomena associated with lucid dreaming and its induction warrant explicit consideration [37, 51, 53]. Sleep paralysis — a transient state in which awareness returns before the muscular atonia of REM sleep has fully dissipated, leaving the individual momentarily unable to move — is more common in lucid dreamers than in the general population and may be triggered or exacerbated by WBTB protocols and by the deliberate cultivation of awareness across the wake–sleep boundary [37, 53]. Although sleep paralysis is generally benign and self-limiting, it can be emotionally distressing, particularly when accompanied by hypnagogic or hypnopompic hallucinations, and may contribute to anxiety surrounding sleep if not adequately explained [37]. False awakenings — episodes in which the dreamer believes that they have woken up while in fact remaining in a dream — represent another phenomenon that may be more frequent among practitioners of lucid dreaming and that can complicate the interpretation of in-dream experiences [37, 51].

The clinical neuroscience of lucid dreaming literature has also drawn attention to potential interactions between lucid dreaming practice and mental-health vulnerabilities [37, 51]. Although lucid dreams have shown therapeutic promise in the treatment of nightmare disorder and post-traumatic stress disorder, and although their cultivation may enhance well-being for many individuals, some authors have cautioned that intensive induction practice may not be appropriate for individuals with severe psychotic vulnerability, dissociative tendencies or untreated affective disorders, where the blurring of waking and dreaming states could conceivably exacerbate symptoms [37]. In an athletic context, where mental-health problems are increasingly recognised as a salient concern, the introduction of LDP should ideally be coordinated with the sport psychologist or medical team, with a baseline assessment of mental-health status and an explicit discussion of the potential phenomenological side effects [37, 55].

A further set of concerns relates to the methodological constraints of measuring LDP outcomes in field settings [6, 45, 56]. Unlike physical practice, which can be quantified through training logs, biomechanical measurements and physiological indices, in-dream rehearsal is largely accessible only through retrospective dream reports, which are subject to memory bias, social desirability and the inherent volatility of dream recall [37, 42, 53]. Polysomnographic verification, while methodologically rigorous, is impractical for routine field use due to its cost, complexity and ecological intrusiveness [11, 17, 53]. Strategies for monitoring LDP in applied contexts therefore typically rely on structured dream diaries, standardised questionnaires (such as the Lucidity and Consciousness in Dreams Scale or the Dream Lucidity Questionnaire) and self-report of in-dream task performance, all of which provide useful but inherently limited information [5, 17, 42].

It is also worth noting that not all lucid dreams are equally amenable to deliberate practice [7, 45, 47]. Among the lucid dreamers studied in survey research, the most common applications of lucid dreaming are recreational — having fun, exploring the dream environment, transforming nightmares into pleasant scenarios — rather than systematic skill rehearsal [42, 52]. Approximately 21% of lucid dreamers in one survey reported using lucid dreams to practice motor skills, and about 9% of lucid dreamers in athletic samples reported using them for sport practice [48, 49, 52]. These figures suggest that, even among those who experience lucid dreams, the proportion who deliberately use them for structured training is comparatively small, and that the cultivation of a disciplined, goal-oriented LDP practice may itself require dedicated effort beyond merely increasing lucid dream frequency [7, 47, 52].

In summary, the practical use of LDP in elite sport must be approached with attention to the limitations of the underlying evidence base, to the potential impact of induction techniques on sleep hygiene and architecture, to the specific phenomenological side effects (sleep paralysis, false awakenings, lucid nightmares), to possible interactions with mental-health vulnerabilities and to the methodological constraints of measuring outcomes in field settings [11, 37, 47, 51, 53, 55]. None of these considerations is necessarily disqualifying, but they collectively underscore the need for a careful, individualised and medically informed implementation, supported by appropriate education and ongoing monitoring of both sleep and mental-health indicators [11, 55, 56].

7.3. Integration of LDP into the training cycle (macrocycle): Proposed placement of dream practice during periods of injury (physiotherapeutic rehabilitation) or before competitions (pre-start stress reduction)

Beyond the question of how to induce lucid dreams safely and reliably, the most pertinent applied question concerns the placement of LDP within the broader structure of athletic preparation [5, 7, 8, 11, 54]. Contemporary periodisation models conceptualise athletic preparation as a series of macrocycles, mesocycles and microcycles, within which training loads, recovery activities and psychological interventions are systematically organised to maximise performance at predetermined competition peaks [8]. Within such a structure, LDP has been proposed as a potentially valuable adjunct in two specific contexts: during periods of injury and rehabilitation, where physical training is constrained but motor learning needs to be preserved; and during the pre-competition phase, where the management of pre-start stress and the consolidation of well-rehearsed skills become priorities [5, 7, 11, 54].

The use of mental training during rehabilitation has been documented in the broader sport psychology literature and offers a natural template for considering LDP within a similar framework [54]. Budnik-Przybylska and Przybylski reported a case study of a Polish national-team sailor preparing for the London 2012 Olympic Games, who underwent a planned anterior cruciate ligament reconstruction after the competitive season and used structured mental training as part of her rehabilitation programme [54]. The authors emphasise the role of mental training in supporting cognitive variables relevant to post-injury adaptation, including the sense of control, self-efficacy and the value placed on rehabilitation, and note that imagery strategies may help motivate athletes to comply with rehabilitation protocols and to sustain confidence in their return to full activity [54]. Although the case study did not involve lucid dream practice specifically, it illustrates how covert rehearsal modalities can be integrated into rehabilitation in a manner that complements physical and physiotherapeutic interventions [54].

The theoretical case for using LDP during injury rehabilitation rests on several converging considerations [5, 7, 24, 33, 47]. First, lucid dream practice activates motor-related brain regions in a manner broadly comparable to waking motor imagery, with the additional advantage of an immersive, first-person sensorimotor context and full corticospinal inhibition that prevents inadvertent loading of injured tissues [39, 40, 47]. Second, sleep-dependent consolidation appears to support the offline retention of skills learned through covert practice modalities, including motor imagery and action observation, suggesting that nightly LDP may contribute to the preservation and refinement of motor memories during periods when physical practice is restricted [16, 33, 34, 36]. Third, LDP may be combined with waking imagery and other psychological interventions — including goal setting, self-talk and relaxation — to address the psychological dimensions of injury, such as anxiety, frustration and loss of identity [1, 2, 54]. Within an injury macrocycle, LDP could thus be tentatively positioned alongside structured waking mental practice, action observation and graduated physical rehabilitation, with the proportion of each modality adjusted according to the phase of recovery [5, 7, 33, 54].

Several caveats apply to this proposed integration [5, 7, 47, 55]. As discussed above, LDP is not a guaranteed modality, and its efficacy is conditional on the frequency of lucid dreams, the dreamer's intra-dream attentional control and the avoidance of distractions [45, 47]. In an injured athlete, additional psychological burdens — including pain, sleep disturbance and emotional distress — may complicate both sleep architecture and the cognitive resources available for structured LDP [54, 55]. Coaches, physiotherapists and sport psychologists who wish to incorporate LDP into a rehabilitation programme should therefore approach it as an optional, complementary adjunct rather than as a primary intervention, and should monitor sleep quality, mental-health symptoms and the athlete's subjective experience of LDP closely [11, 37, 54, 55].

The pre-competition phase represents a second potential context for LDP, with a somewhat different rationale [5, 7, 11]. In the days and weeks leading up to important competitions, athletes typically undergo tapering protocols in which training volumes are reduced while specific skill rehearsal and psychological preparation are emphasised [8]. The pre-competition phase is also characterised by elevated psychological arousal, occupying thoughts, anticipatory anxiety and, frequently, disturbed sleep [11, 12]. Several authors have noted that lucid dreams may provide a means of mentally rehearsing competitive scenarios in a controlled, low-load fashion, and may also support strategies for managing pre-start stress through the deliberate manipulation of dream content — for instance, by rehearsing successful performance, exposing oneself to difficult competitive scenarios in a safe environment or practising relaxation within the dream [2, 7, 56]. The qualitative case study by Ableidinger and Holzinger of a martial-arts practitioner illustrates how lucid dreams can be used not only to rehearse specific techniques but also to explore the affective and tactical dimensions of competition, contributing to the development of confidence and adaptive flexibility [56].

From a practical standpoint, the integration of LDP into the pre-competition phase should respect the primacy of sleep health [11, 51, 55]. Any induction technique that fragments sleep — most notably WBTB — should be avoided in the immediate run-up to competition, when consolidation of physical and mental energy is paramount, and should be reserved for earlier phases of preparation when occasional sleep disruption is more easily absorbed [11, 51, 53]. Less disruptive techniques, such as MILD and reality testing, may be more compatible with the pre-competition phase, particularly if they have already been embedded in the athlete's routine during the preparatory period [5, 53, 56]. The aim of LDP in this phase is generally not to maximise the number of lucid dreams but rather to maintain a degree of mental engagement with the competitive task while preserving the integrity of recovery and sleep [7, 11, 47, 55].

A third potential context for LDP — although less developed in the literature — is its possible role during off-season or transition phases [5, 7, 56]. During these periods, athletes typically reduce structured training and may use the time for skill exploration, technical refinement and the integration of new movements. Lucid dreams have been described qualitatively as a setting in which athletes can experiment with novel techniques and tactical solutions that would be difficult to attempt in waking practice due to fatigue, risk of injury or environmental constraints [7, 56]. The case study by Ableidinger and Holzinger reports that lucid dreams allowed a martial-arts practitioner to "explore new movements and new possibilities" beyond what waking practice afforded, and to test creative tactical responses in a safe environment [56]. From a periodisation standpoint, the off-season may thus represent a relatively low-risk window in which to introduce LDP and to develop the requisite induction and dream-control skills, before deciding whether and how to deploy them during the more demanding phases of the macrocycle [7, 56].

The integration of LDP into a structured training cycle also raises practical questions regarding the personnel and protocols involved [11, 47, 55, 56]. Given the multidisciplinary nature of contemporary sport science, the introduction of LDP would typically benefit from collaboration between coaches, sport psychologists, physiotherapists and, where relevant, sleep specialists [8, 11, 55]. The role of the coach is to articulate the technical and tactical goals of the training cycle and to identify junctions at which LDP may complement physical practice; the role of the sport psychologist is to provide guidance on imagery techniques, attentional control and induction protocols; the role of the physiotherapist is particularly salient in injury contexts, where LDP may be coordinated with rehabilitation exercises and pain-management strategies; and the role of the sleep specialist, where available, is to monitor and protect the integrity of the athlete's sleep architecture [11, 53, 54, 55]. The integration of these contributions into a coherent intervention requires structured communication, clear documentation of the LDP programme and ongoing reassessment based on the athlete's response [8, 11, 55].

Although the present chapter has focused primarily on the athletic context, the conceptual framework outlined here may be transferred, with appropriate modifications, to other domains in which motor learning and performance under pressure are relevant — including surgical training, musical performance, dance, and the rehabilitation of patients with neurological disorders [4, 22, 24, 56]. In each of these domains, the same general principles apply: induction techniques must be selected with care, the impact on sleep architecture must be respected, the cultivation of dream control should accompany the increase in lucid dream frequency, and the integration of LDP into the broader training or rehabilitation programme should be planned in consultation with the relevant multidisciplinary team [11, 47, 53, 56].

In conclusion, the proposed integration of lucid dream practice into the macrocycle of athletic preparation should be understood as exploratory rather than prescriptive [5, 7, 47, 53, 56]. The available evidence supports the view that LDP may complement classical mental practice and physical training, particularly during periods of injury and pre-competition tapering, but the relatively small number of controlled studies, the variability of individual responses and the methodological and ethical considerations associated with sleep manipulation argue for a cautious, individualised and well-monitored approach [5, 6, 11, 45, 53, 55, 56]. Within this framework, LDP emerges not as a stand-alone "magic bullet" for performance enhancement but as one of several potential adjuncts that may, under appropriate conditions and with appropriate safeguards, contribute to the multidimensional preparation of the contemporary athlete [5, 7, 8, 11, 56].

8. Discussion and Limitations

The body of evidence synthesised in the preceding chapters supports a relatively coherent, if still incompletely developed, narrative regarding the relationship between motor imagery in wakefulness, sleep-dependent consolidation of procedural memory, the neurobiology of lucid dreaming and the practical implications of lucid dream practice (LDP) for athletic preparation [3, 5, 14, 15, 17]. At the level of waking motor imagery, the literature converges on the view that imagined and executed movements share, to a substantial degree, the neural substrates and representational formats that subserve motor planning, motor preparation and motor control, including premotor cortex, supplementary motor area, posterior parietal regions, basal ganglia and cerebellum [3, 19, 20, 21, 22, 24]. This functional equivalence, although not identity, is supported by neuroimaging, electrophysiological, behavioural and autonomic measures, and provides the conceptual foundation for the use of motor imagery as a training modality across sport, surgery, music and rehabilitation contexts [22, 23, 24, 27]. Importantly, the literature also emphasises that visual and kinesthetic imagery may engage partially separable neural networks, and that the perspective from which imagery is conducted — first-person or third-person — modulates both the phenomenology and the topography of neural activation, with practical consequences for the design of imagery-based interventions [19, 20, 21, 25].

A parallel and increasingly mature body of work has established that sleep is not a passive recovery interval but rather an active process that supports the offline consolidation of motor memories [14, 15, 16, 24, 29, 33, 36]. Within this framework, slow-wave sleep and rapid-eye-movement sleep appear to make complementary contributions, with thalamocortical sleep spindles, hippocampal sharp-wave ripples and cortical slow oscillations supporting system-level consolidation during slow-wave sleep, while REM sleep — characterised by high cholinergic and theta activity — appears to favour synaptic consolidation and the integration of memories into pre-existing cortical networks [15, 29, 30, 43]. Behavioural studies in healthy populations have demonstrated overnight performance gains on motor tasks after sleep but not after equivalent periods of wakefulness, with effects that depend on task type, the temporal proximity of training and sleep, and the structure of practice (constant versus variable) [14, 16, 31, 35]. The application of these findings to motor imagery and action observation suggests that the offline benefits classically associated with physical practice may extend, at least in part, to covert practice modalities, providing a mechanistic bridge between waking imagery and dream-based rehearsal [16, 24, 33, 34].

The neurobiological characterisation of lucid REM sleep, in turn, provides the conceptual link between waking imagery and sleep-based rehearsal [17, 39, 41]. Lucid REM sleep appears to combine the sensorimotor and physiological characteristics of REM sleep with partial reactivation of prefrontal and parietal regions associated with metacognition, self-reflection and volitional control [17, 41, 44]. Eye-signal verification, fMRI and NIRS studies have shown that dreamed motor actions elicit activations in the sensorimotor cortex and supplementary motor area comparable to those observed during waking motor imagery, while autonomic measurements have demonstrated heart-rate and respiratory adjustments during dreamed exercise that mirror, albeit in attenuated form, those observed during overt exertion [38, 39, 40]. The paradox of muscular atonia — in which the motor cortex generates a descending command that is blocked at the brainstem and spinal level — creates a unique configuration in which the brain may engage in deliberate rehearsal without producing overt motor output, with potential implications for training, rehabilitation and recovery [22, 39, 40].

The empirical literature on lucid dream practice in athletes is, however, considerably more limited than the literature on motor imagery in wakefulness or on sleep-dependent consolidation of physically learned skills [5, 6, 7, 45]. Three quantitative studies — using coin tossing, finger tapping and dart throwing — have shown that LDP can produce measurable improvements in subsequent waking performance, with effects broadly comparable to those of waking mental practice and possibly smaller than those of full physical practice [6, 45]. Qualitative and survey-based work has confirmed that a subset of athletes already uses lucid dreams for sport rehearsal and reports subjective improvements, with cross-cultural data suggesting that the phenomenon is not confined to any single national or sporting tradition [7, 48, 49, 51]. At the same time, the literature has repeatedly emphasised that the efficacy of LDP is conditional on factors such as intra-dream attentional focus, dream stability, dream control, self-efficacy and the appropriate selection of the task to be rehearsed [7, 45, 47]. Recent meta-analytical work synthesising the available quantitative studies has suggested a medium positive effect size of LDP on motor performance, although this effect did not reach statistical significance, reflecting the small number of studies and the wide confidence intervals [56].

Several limitations of the present narrative review and of the underlying literature should be made explicit [17, 37, 53, 56]. First, the very narrative format chosen here precludes a formal meta-analytic aggregation of effect sizes and depends on a synthesis of methodologically heterogeneous studies, with all the interpretive risks that this entails. The choice of this format was guided by the conceptual breadth of the topic and by the limited number of strictly comparable empirical studies, but a future systematic review and meta-analysis focused on a more narrowly defined subset of LDP studies would be a valuable complement to the present synthesis [53, 56].

Second, the underlying empirical literature on lucid dream practice in athletes is characterised by small sample sizes, heterogeneous tasks, varied induction techniques and a paucity of laboratory-controlled trials [6, 17, 45, 47, 53]. Even the most rigorous available studies — including the sleep-laboratory study by Schädlich and colleagues — have enrolled fewer than ten participants per condition, partly due to the rarity of the phenomenon and the difficulty of inducing lucidity reliably in the constrained environment of a sleep laboratory [37, 45]. As a consequence, individual differences in lucid dream frequency, dream control, imagery ability and self-efficacy can have a disproportionate influence on the group-level findings, and the generalisability of the existing studies to elite athletic populations remains uncertain [47, 56].
Third, the methodological tools available for measuring in-dream behaviour are inherently limited [37, 45, 47]. Although eye-signal verification, fMRI and NIRS have transformed the field by providing objective temporal markers and neural correlates, the detailed characterisation of in-dream rehearsal still depends substantially on retrospective dream reports, which are subject to memory bias, social desirability and the inherent volatility of dream recall [37, 42]. The development of more standardised qualitative coding schemes for in-dream behaviour, the integration of polysomnographic markers with structured dream interviews and the use of repeated within-subject designs may help to refine the characterisation of intra-dream attentional control and distraction in future work [37, 45, 47].

Fourth, the literature on lucid dreaming has been criticised for a tendency to focus disproportionately on the achievement of lucidity itself, while paying less attention to the equally important skill of dream control and to the cultivation of structured, distraction-free rehearsal within the dream [37, 47]. Peters and colleagues have argued that this imbalance has important practical implications, since the efficacy of LDP appears to depend at least as strongly on dream control and self-efficacy as on lucid dream frequency [47]. Future studies should therefore investigate whether dream control can itself be trained, the conditions under which such training is effective, and the relationship between trait-level psychological variables — including self-efficacy, attentional control and emotional regulation — and the capacity for structured in-dream rehearsal [37, 47].

Fifth, the literature on the safety and side effects of intensive lucid dream induction in elite athletic populations remains comparatively underdeveloped [11, 37, 51, 53, 55]. While general considerations regarding sleep paralysis, false awakenings, lucid nightmares and the impact of WBTB on sleep architecture have been discussed, systematic data on the prevalence and management of these phenomena among athletes who actively practise LDP are scarce [37, 51, 55]. Given the large-scale evidence that approximately one in four elite athletes already exhibits symptoms suggestive of clinically relevant sleep disorders, the introduction of any practice that may further compromise sleep architecture must be approached with caution, and additional research on the interaction between LDP and sleep health in athletic populations is needed [11, 55].

Sixth, the language restriction of the present review — to peer-reviewed publications in English and selected Polish-language sources — represents an additional limitation that should be acknowledged. Although the major journals in sport science, sleep medicine and consciousness research publish predominantly in English, relevant work may exist in other languages, particularly in cultural contexts where contemplative sleep practices (such as dream yoga and Yoga Nidra) have a long history [37, 44]. Future reviews could usefully broaden the linguistic and cultural scope of the literature search.

Seventh, the rapidly evolving methodological landscape of consciousness research — including new advances in EEG microstate analysis, simultaneous EEG–fMRI recordings, transcranial stimulation and pharmacological probes — suggests that the present synthesis may be partially superseded by findings reported in the coming years [17, 30, 37, 41, 44]. The integration of these new methodologies into the study of LDP in athletic populations represents both an opportunity and a challenge, and underscores the provisional nature of any current synthesis [37, 41, 44, 56].

Despite these limitations, the convergence of evidence across motor imagery research, sleep-dependent memory consolidation, the neurobiology of lucid REM sleep and the empirical literature on LDP in athletes provides a coherent conceptual framework within which the possibility of sleep-based motor rehearsal can be discussed without recourse to speculation [3, 14, 15, 17, 24, 33]. Within this framework, LDP emerges as a plausible — although still incompletely characterised — adjunct to conventional training and mental practice modalities, particularly in contexts where physical practice is constrained, such as injury, tapering or specific phases of the competitive macrocycle [5, 7, 54, 56]. The careful integration of LDP into structured athletic preparation, supported by individualised induction protocols, attention to sleep hygiene, multidisciplinary collaboration and ongoing monitoring of mental-health indicators, may allow some athletes to benefit from this modality while minimising the risks associated with its inappropriate use [11, 47, 53, 55, 56].

9. Summary and conclusions

9.1. A brief synthesis of the main findings of the work

The present narrative review has integrated the neurophysiological, behavioural and applied literature on motor imagery in wakefulness, the architecture of sleep and its role in the consolidation of motor memory, the neurobiology of lucid dreaming and the use of lucid dream practice as an emerging modality in athletic preparation and rehabilitation [1, 2, 3, 5, 8, 14, 15, 17]. The synthesis can be summarised in five main observations.

First, motor imagery in wakefulness appears to engage cortical and subcortical motor networks largely overlapping with those active during overt action, with measurable autonomic correlates that support its conceptualisation as a "real" event for the nervous system [3, 19, 20, 22, 23, 24, 27]. Visual and kinesthetic imagery, and first- and third-person perspectives, may recruit partially separable neural networks, and the choice of modality and perspective has non-trivial implications for the efficacy of mental practice interventions [19, 20, 21, 25, 26].

Second, sleep — particularly slow-wave sleep and REM sleep — supports the offline consolidation of motor memory through coordinated patterns of cortical slow oscillations, thalamocortical sleep spindles and hippocampal sharp-wave ripples, with neuromodulatory mechanisms favouring system consolidation and synaptic consolidation, respectively [14, 15, 29, 30]. The behavioural literature in healthy adults has consistently demonstrated overnight performance gains on motor tasks after sleep but not after equivalent periods of wakefulness, with effects that depend on task complexity, the temporal proximity of training and sleep, and the structure of practice [14, 16, 31, 33, 35, 36].

Third, lucid REM sleep represents a distinctive state of consciousness in which several features classically associated with wakefulness — including metacognitive insight, volitional control and partial prefrontal engagement — coexist with the sensorimotor immersion and physiological characteristics of REM sleep [17, 41, 44]. Eye-signal verification, fMRI and NIRS studies have provided direct evidence that dreamed motor actions activate the sensorimotor cortex and supplementary motor area in a manner comparable to waking motor imagery, while autonomic and electromyographic measurements have demonstrated partial peripheral correlates of dreamed action [38, 39, 40]. The paradox of muscular atonia — in which the motor cortex generates a descending command that is blocked at the brainstem level — creates a state in which the brain may simulate movement without producing it, providing a substrate for deliberate in-dream rehearsal [22, 39, 40].

Fourth, the empirical literature on lucid dream practice in athletes, while still limited in size, suggests that LDP may produce measurable improvements in subsequent waking performance for certain motor tasks, with effects broadly comparable to those of waking mental practice and conditional on factors such as intra-dream attentional focus, dream control and self-efficacy [5, 6, 7, 45, 47]. Survey data from German, Japanese and adolescent athletic populations indicate that a non-trivial proportion of athletes already experience lucid dreams and that a subset deliberately uses them for sport practice, with subjectively perceived improvements in waking performance [48, 49, 51].

Fifth, the practical integration of LDP into athletic preparation appears to be feasible but methodologically and ethically demanding [11, 47, 53, 55, 56]. The choice of induction techniques should balance efficacy against the risk of sleep fragmentation; the cultivation of dream control should accompany the increase in lucid dream frequency; potential phenomenological side effects (sleep paralysis, false awakenings, lucid nightmares) and interactions with mental-health vulnerabilities should be considered; and the placement of LDP within the macrocycle — particularly during injury rehabilitation and pre-competition tapering — should be planned in collaboration with the multidisciplinary team supporting the athlete [11, 37, 53, 54, 55, 56].

Taken together, these observations support the view that lucid dream practice constitutes a neurophysiologically grounded, behaviourally promising but still incompletely characterised modality, whose role in contemporary athletic preparation should be approached as exploratory and complementary rather than as a substitute for physical practice or waking mental training [5, 7, 56].

9.2. Evaluation of the responses to the research questions

The five research questions articulated in Chapter 1 may be addressed in the light of the synthesis above.

The first question concerned the degree of neural and functional overlap between imagined and executed actions and the extent to which this overlap may be invoked to justify mental practice as a training modality. The reviewed evidence indicates that motor imagery activates a network of motor-related brain regions — including premotor cortex, supplementary motor area, parietal cortex, basal ganglia and cerebellum — that substantially overlaps with the network activated during overt motor execution, although it is not identical [3, 19, 20, 21, 22, 24]. The temporal, autonomic and electromyographic correlates of imagery further support the notion of functional equivalence between covert and overt action, with the caveat that this equivalence operates at the neural and representational level rather than at the level of behavioural identity [3, 19, 22, 27]. The functional equivalence hypothesis thus provides a robust conceptual foundation for the use of motor imagery as a training modality, and by extension for its further extension into the dreaming brain [3, 22, 39].

The second question concerned the contribution of distinct sleep stages to the consolidation and reorganisation of procedural memory traces. The reviewed evidence supports the view that slow-wave sleep and REM sleep make complementary contributions to memory consolidation, with the former primarily supporting system-level consolidation through hippocampal–neocortical dialogue and the latter contributing to synaptic consolidation and the integration of memories into cortical networks [15, 29, 30]. In the motor domain, stage 2 NREM sleep — and particularly the density of sleep spindles — has been repeatedly associated with overnight improvements in finger-tapping performance, while REM sleep has been implicated in the consolidation of complex motor skills and in the experience-dependent reactivation of motor-related cortical regions [14, 33, 36, 43]. Although individual contributions of specific sleep stages remain debated and may depend on task type and individual variability, the overall picture is consistent with a model in which sleep, in its various forms, provides a privileged environment for the offline reorganisation and reinforcement of motor memory traces [14, 15, 33].

The third question concerned the neurobiological substrates of lucid dreaming itself and the verifiability of the phenomenon through electrooculographic and neuroimaging methods. The reviewed evidence supports the view that lucid dreaming is a verifiable, REM-sleep-based phenomenon, with eye-signal verification serving as the gold standard since the foundational work of LaBerge and colleagues [38]. Neuroimaging studies have linked lucid REM sleep to partial reactivation of prefrontal and parietal regions associated with metacognition and self-reflection, while EEG microstate analyses suggest distinctive network dynamics involving altered visual processing, executive function and default-mode-network activity [17, 39, 41]. The combination of these methods provides converging evidence that lucid dreaming is a genuine state of consciousness within sleep, with neurobiological signatures that justify its consideration as a unique experimental and applied context [17, 39, 41, 44].

The fourth question concerned the behavioural and applied evidence on lucid dream practice in athletes, including comparisons with physical and mental practice and the role of intra-dream factors. The reviewed evidence supports a cautiously optimistic appraisal: three quantitative studies have demonstrated measurable improvements in subsequent waking performance after LDP on simple motor tasks, with effects comparable to those of waking mental practice and possibly smaller than those of physical practice [6, 45]. Qualitative and survey-based work confirms that a non-trivial subset of athletes already engages in LDP and reports perceived improvements, with cross-cultural data suggesting some generalisability [7, 48, 49, 51]. However, the efficacy of LDP appears to be conditional on intra-dream attentional focus, dream stability, dream control and the avoidance of distractions, all of which vary substantially across individuals and across dreams within the same individual [45, 47]. Meta-analytical work suggests a medium positive effect size that does not yet reach statistical significance, underscoring the need for additional, larger and more methodologically rigorous studies [56].
The fifth question concerned the practical, methodological and ethical implications of integrating lucid dream practice into the work of coaching staff, sport psychologists and rehabilitation teams. The reviewed evidence indicates that LDP may, under appropriate conditions, be a useful adjunct to conventional training and mental practice modalities, particularly during periods of injury rehabilitation and pre-competition tapering [5, 7, 54, 56]. However, its implementation requires careful attention to the choice of induction techniques (favouring less sleep-disruptive options such as MILD and reality testing over more disruptive approaches such as WBTB during high-load periods), to the protection of sleep architecture, to the management of potential phenomenological side effects and interactions with mental-health vulnerabilities, and to the broader integration of the practice within a multidisciplinary athletic support framework [11, 37, 51, 53, 55, 56]. Across all these considerations, the recurring theme is one of cautious individualisation: LDP should not be promoted as a universal performance-enhancement tool but rather as a potentially valuable modality whose use, monitoring and integration should be tailored to the specific athlete, sport and phase of the macrocycle [5, 7, 47, 56].

9.3. Directions for future research

Several directions for future research emerge from the present synthesis [37, 53, 55, 56]. First, there is a clear need for larger, methodologically rigorous studies of lucid dream practice in elite athletic populations, employing polysomnographically verified lucid dreams, standardised motor tasks, structured pre-sleep imagery protocols and adequate control conditions [6, 17, 45, 56]. The relative scarcity of laboratory-controlled trials in this area constitutes one of the main barriers to a more definitive appraisal of LDP, and the development of multi-centre studies — possibly leveraging consortia of sleep laboratories specialising in lucid dream research — may help to overcome the small-sample limitations of single-laboratory work [17, 53, 56].

Second, future research should pay more systematic attention to the distinction between lucid dream frequency and dream control, and to the training of intra-dream attentional and regulatory skills [37, 47]. Although a substantial literature exists on induction techniques, the corresponding literature on dream control training is comparatively underdeveloped, and the conditions under which dream control can be trained, the time course of such training and the relationship to individual differences in self-efficacy, attentional control and meta-awareness require further investigation [37, 47]. Studies combining structured pre-sleep imagery interventions with in-laboratory polysomnography and post-dream interviews may help to clarify these relationships [37, 47].

Third, the integration of EEG microstate analysis, simultaneous EEG–fMRI, transcranial stimulation and emerging neuroimaging techniques into the study of lucid REM sleep may provide important new insights into the neural correlates of dreamed motor action and into the mechanisms by which intra-dream practice may translate into waking performance gains [17, 30, 41, 44]. The development of more accurate models of the relationship between dreamed action, sleep architecture and post-sleep performance — incorporating both online (in-dream) and offline (post-sleep) consolidation processes — would represent a significant advance [16, 24, 33].

Fourth, the safety and ethical dimensions of LDP in athletic populations require systematic empirical attention [11, 37, 55]. Prospective studies monitoring sleep architecture, subjective sleep quality, mental-health symptoms and the prevalence of side effects (sleep paralysis, lucid nightmares, false awakenings) in athletes engaged in structured LDP would provide an evidence-based foundation for the development of practice guidelines and for the identification of contraindications [11, 37, 51, 55]. The large-scale data on sleep disorders in elite athletic populations underscore the importance of integrating any LDP intervention into a broader sleep-health framework [11, 55].

Fifth, the applied translation of LDP into structured training programmes calls for collaborative work between sport psychologists, coaches, physiotherapists and sleep specialists, and for the development of practical protocols suited to the specific demands of different sports and phases of the macrocycle [7, 8, 54, 56]. Pilot studies in injury rehabilitation settings, where physical training is constrained but motor learning remains essential, may represent a particularly fruitful starting point, drawing on the existing literature on mental practice in clinical rehabilitation as a template [4, 24, 33, 34, 54]. Studies in pre-competition contexts, focusing on the use of LDP for stress regulation, scenario rehearsal and confidence building, may further illuminate its psychological as well as motor dimensions [2, 7, 51, 56].

Sixth, the broader cultural and contemplative context of lucid dreaming — including its long history in dream yoga, Yoga Nidra and related contemplative traditions — represents a relatively underexplored interface that may inform both the cultivation and the conceptualisation of LDP in athletic and clinical contexts [37, 44]. Cross-disciplinary work bridging consciousness research, contemplative studies and sport science may help to enrich both the theoretical and practical understanding of lucid dream practice [44].

Seventh, the methodological tools available for measuring in-dream behaviour and intra-dream attentional control require further refinement [37, 45, 47]. The development and validation of standardised dream-report coding schemes, in-dream task protocols and quantitative indices of dream control would facilitate cross-study comparison and meta-analytic aggregation, contributing to a more cumulative scientific literature in this area [37, 47, 56].

Finally, attention should be paid to the long-term sustainability of LDP practices in elite athletes, including the maintenance of induction skills, the avoidance of dependence on sleepdisrupting techniques, the prevention of lucid-dream-related anxiety and the protection of overall sleep health across the athletic career [11, 37, 51, 55]. Longitudinal studies tracking athletes who incorporate LDP into their preparation over several seasons, monitoring both performance and health indicators, would provide important data on the ecological validity and durability of the approach [11, 55, 56].

In conclusion, the present narrative review has sought to synthesise a relatively dispersed but methodologically rich body of literature, in the hope of stimulating an informed and prudent discussion of the role of motor imagery in REM sleep and lucid dreaming in the optimisation of motor memory consolidation in athletes [3, 5, 14, 15, 17, 24]. While the available evidence supports the view that lucid dream practice may, under appropriate conditions, contribute to the multidimensional preparation of contemporary athletes, the field remains in a relatively early stage of development, and definitive conclusions await further empirical work [6, 7, 45, 56]. The convergence of neurophysiological, behavioural and applied evidence, however, suggests that the dreaming brain — and in particular the lucid REM sleep state — represents a genuinely promising frontier for the cognitive sciences of sport, with potential applications that extend beyond athletic performance to the broader domains of rehabilitation, clinical practice and the science of consciousness [5, 17, 37, 44, 56].

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The author used generative AI tools (Google Gemini) during the preparation of this manuscript for structuring the text, translating content, and formatting citations. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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