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REVIEW

Flow-Induced Analgesia: A Conceptual Review of Biopsychosocial and Neurobiological Mechanisms of Pain Modulation

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Background: Chronic pain remains one of the leading causes of disability worldwide and is strongly influenced by attentional and cognitive-emotional factors such as catastrophizing and hypervigilance. While distraction techniques (eg, virtual reality, music) and mindfulness-based approaches are established adjuncts in pain management, the psychological construct of flow—a state of deep absorption and effortless concentration described by Csikszentmihalyi—has not yet been systematically explored in pain medicine. Flow represents an optimal attentional state characterized by balance between skill and challenge, loss of self-focus, and intrinsic reward.

Objective: This review aims to (1) synthesize existing evidence linking flow states with pain perception and modulation, (2) outline potential neurobiological mechanisms, and (3) propose a conceptual framework—flow-induced analgesia—as a novel pathway for future pain interventions.

Methods: A structured literature search was conducted in PubMed, Scopus, Web of Science, and PsycINFO from 2000–2024 using Boolean (AND/OR) operators and Medical Subject Headings (MeSH) terms. Approximately 700 records were identified, of which 40 conceptually relevant peer-reviewed studies from psychology, neuroscience, and pain medicine were included across domains such as virtual reality, music, sports, and rehabilitation. The evidence base was integrated qualitatively due to heterogeneity and conceptual scope.

Results: Evidence from experimental pain studies, virtual reality analgesia, music, and rehabilitation demonstrates that immersive attentional states can reliably reduce pain perception. Flow-related neuroimaging research shows suppression of default mode network activity and activation of attentional and reward circuits, overlapping with mechanisms of descending pain modulation. Preliminary clinical studies suggest that individuals with higher dispositional flow experience less pain interference.

Conclusion: Flow states may represent a natural analgesic mechanism, extending beyond simple distraction by engaging attentional, motivational, and reward systems. Conceptualizing flow-induced analgesia provides a testable framework for novel clinical interventions in pain medicine, including VR (virtual reality), gamified rehabilitation, and arts-based therapies. Further research is required to validate flow-based interventions through randomized controlled trials and neuroimaging studies. This conceptual framework extends current understanding of pain modulation by identifying flow as a distinct, testable, and integrative mechanism of analgesia.

Keywords: chronic pain, pain modulation, attention, motivation, reward system, flow state

Introduction

Chronic pain is among the most significant public health challenges worldwide, affecting approximately 20% of adults and representing a leading cause of disability and loss of productivity.[1,2] Persistent pain is not merely a sensory phenomenon, but a complex biopsychosocial experience shaped by attentional, emotional, and cognitive factors. Contemporary models highlight the importance of pain-related attention, catastrophizing, hypervigilance, and impaired coping strategies as central determinants of pain intensity and interference.[3,4] These insights have stimulated the

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integration of cognitive-behavioral, mindfulness-based, and distraction-oriented strategies into multimodal pain management.[5,6]

For conceptual clarity, this review adopts the International Association for the Study of Pain[7] definitions distinguishing among chronic, persistent, recurrent, and acute pain.

Chronic pain refers to pain lasting longer than three months; persistent pain describes continuous or unremitting pain without remission periods; and recurrent pain refers to repeated episodes separated by pain-free intervals. The studies included in this review predominantly involved individuals with chronic and persistent pain (eg, fibromyalgia, musculoskeletal, and neuropathic conditions), while a smaller number used acute experimental pain paradigms to investigate underlying mechanisms.

Distinguishing these categories is important, as the underlying mechanisms of pain modulation may differ between acute, recurrent, and persistent forms.

Within this context, flow, a psychological construct introduced by Csikszentmihalyi in the 1970s,[8] describes an optimal state of consciousness characterized by deep absorption, intrinsic motivation, and a balance between task challenge and individual skill.

Flow represents one of the most powerful and immersive psychological states, capable of profoundly altering perception, attention, and affective experience. It has been extensively investigated in domains such as performance, sports, education, and creativity, where it has been associated with positive affect, intrinsic reward, and enhanced task engagement. However, flow has not yet been systematically examined in relation to pain modulation, and its potential relevance within clinical and neurobiological frameworks of pain remains largely unexplored. This conceptual gap provides the rationale for examining flow as a possible psychological and neurocognitive mechanism contributing to pain modulation.

Flow describes an optimal state of consciousness characterized by total absorption in an activity, a balance between skills and task challenge, diminished self-referential processing, altered sense of time, and intrinsic reward.[6,8] Unlike passive distraction, flow implies active engagement and effortless attention, accompanied by positive affect and heightened performance.[9] Flow has been studied extensively in sports, music, education, and work performance, but its potential role in clinical domains, particularly in chronic pain, remains largely unexplored.[10,11]

Understanding how flow influences pain has clinical relevance, since flow-inducing activities such as immersive virtual-reality therapy, music engagement, and rehabilitation games are already used to improve patient adherence and reduce pain-related distress in clinical contexts.[12,13]

To avoid conceptual overlap, the distinction between distraction and flow was clarified.

Distraction involves a temporary shift of attention away from pain, which can be passive (eg, watching television) or active (eg, playing a simple game), but it does not necessarily engage intrinsic motivation or deep absorption. In contrast, flow represents a state of intense, sustained, and intrinsically rewarding engagement, characterized by clear goals, balance between skill and challenge, immediate feedback, and a loss of self-consciousness. Thus, while both phenomena can reduce pain perception, flow implies higher-order cognitive–affective integration that distinguishes it from mere attentional redirection.

The neurocognitive correlates of flow partly overlap and may interact with known mechanisms of pain modulation. Neuroimaging studies demonstrate that flow states are associated with suppression of default mode network (DMN) activity, reduced self-referential processing, and enhanced activation of task-positive networks, including the dorsal attention network and reward-related circuitry.[14,15] These networks are critically involved in the perception and modulation of pain, suggesting that flow may counteract maladaptive patterns such as rumination and catastrophizing.[16] Furthermore, dopaminergic signaling and striatal activation during flow[17] align with mechanisms of descending inhibitory control and analgesic placebo responses.[18] Thus, flow may represent a potential natural analgesic state, engaging attentional, motivational, and reward pathways.

Although the neural overlap between flow and descending pain inhibition is intriguing, current evidence remains correlational rather than causal. Most studies demonstrating flow-related modulation of pain rely on subjective ratings or indirect neuroimaging markers and do not establish directionality between neural activity and analgesic outcomes.

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Therefore, the relationship between flow and descending inhibitory control should be regarded as a testable hypothesis, not a confirmed mechanism.

Several key questions remain unanswered. In particular, it is unclear whether suppression of the DMN during flow causally mediates analgesic effects in chronic pain populations. Existing experimental pain paradigms and clinical neuroimaging data demonstrate association but not causation. Future longitudinal and mechanistic studies are needed to determine whether flow-induced DMN modulation directly contributes to pain relief.

To illustrate these relationships, a compact schematic Supplementary Figure S1 was added, cross-walking core psychological constructs of flow (attention, motivation, reward, embodiment) with their predicted neural signatures and potential analgesic mechanisms.

Indirect evidence supports this proposition. Immersive virtual reality interventions, which induce flow-like states through interactive and adaptive environments, have consistently demonstrated analgesic effects in both acute and chronic pain populations.[19,20] Similarly, music engagement, artistic activities, and sports have shown pain-reducing potential, often interpreted through attentional and affective mechanisms but possibly attributable to flow experiences.[21,22] In rehabilitation, patient motivation and adherence to the treatment plan is vital, higher adherence is linked with stronger autonomous motivation, motivated and supported patients overall show better rehabilitation results.[23] It could be argued that if rehabilitation process included activities that are likely to induce flow state, the patient adherence to rehabilitation plan would likely increase.

The pain-relieving effects of physical activity likely emerge from an interplay between physiological and psychological processes. Physiological responses such as endorphin and endocannabinoid release, improved circulation, and activation of periaqueductal gray (PAG) and rostral ventromedial medulla (RVM) pathways contribute to descending modulation.[24–26]

Concurrently, psychological mechanisms—intrinsic motivation, perceived competence, attentional absorption, and positive affect—reinforce these effects via dopaminergic reward circuits. Flow may represent an integrative state that unites these physiological and cognitive–affective dimensions within one adaptive mechanism of analgesia.

However, despite these promising links, no systematic attempt has been made to conceptualize flow as a distinct therapeutic mechanism in pain medicine.

We propose the term flow-induced analgesia (FIA) to describe this framework. Flow-induced analgesia suggests that immersive, skill-challenge balanced activities can actively modulate pain perception and interference through attentional capture, suppression of self-referential cognition, engagement of reward circuits, and activation of descending pain modulatory systems. This concept extends beyond distraction and mindfulness by emphasizing the active, autotelic nature of flow and its potential for cumulative benefits in chronic pain management.

This conceptual framework should therefore be regarded as a working hypothesis, integrating converging evidence from psychology, neuroscience, and pain research.

This conceptual framework also extends beyond earlier integrative models, such as the fear-avoidance model and motivational-affective frameworks, which primarily emphasize maladaptive avoidance and affective regulation.

FIA instead focuses on adaptive engagement and intrinsic motivation, highlighting how attentional absorption and reward-driven mastery can counteract avoidance and negative affect.

Thus, FIA complements rather than replaces existing models by providing a positive, self-reinforcing mechanism of pain modulation.

The aim of this review is therefore threefold: (1) to synthesize current evidence linking flow states with pain perception, (2) to outline neurocognitive and affective mechanisms that may underline flow-induced analgesia, and (3) to propose future directions for clinical research and interventions. By integrating insights from psychology, neuroscience, and pain medicine, this review seeks to provide a novel conceptual framework for harnessing flow in multimodal approaches to chronic pain.

Methods of Literature Search

This article was designed as a conceptual narrative review with structured scoping elements, rather than a systematic or full scoping review. Nevertheless, a transparent and structured approach to evidence identification was applied to ensure reproducibility and conceptual rigor.

A structured literature search was performed in PubMed, Scopus, Web of Science, and PsycINFO databases covering the period from January 2000 through June 2024.

Boolean operators (AND, OR) and Medical Subject Headings (MeSH) terms were applied to ensure comprehensive and reproducible retrieval of literature. The representative PubMed search string was:

("flow state" OR "flow experience" OR "psychological flow" OR "immersion") AND ("pain" OR "analgesia" OR "pain modulation" OR "nociception") AND ("virtual reality" OR "music" OR "rehabilitation" OR "exercise" OR "attention").

Search fields were refined using MeSH descriptors such as Pain [MeSH], Analgesia [MeSH], and Attention [MeSH]. Equivalent keywords and subject terms were used for PsycINFO, ensuring coverage of psychological and behavioral studies relevant to flow and pain. Studies were included only when the flow experience was assessed using validated psychometric instruments, such as the Flow State Scale (FSS/FSS-2), Dispositional Flow Scale (DFS), or Flow Short Scale (FSS-10).

These measures ensure that participants demonstrated core characteristics of flow—absorption, intrinsic reward, and reduced self-referential processing—rather than simple distraction or task engagement.

Reference lists of included papers and prior reviews were manually screened to identify additional relevant publications.

The initial search yielded over 700 records. Articles were included if they met the following criteria:

1. peer-reviewed and published in English
2. examined flow-related constructs, immersive engagement, or attentional modulation in the context of pain or rehabilitation
3. provided empirical, neurobiological, or theoretical relevance to mechanisms of pain modulation.

Exclusion criteria comprised non-English language, conference abstracts, non–peer-reviewed sources, and publications not addressing pain mechanisms or attentional engagement. Gray literature and preprint sources were excluded to maintain methodological consistency and data reliability.

Formal quality or bias assessment was not performed, consistent with the conceptual narrative design. After screening for conceptual and methodological relevance, approximately 40 peer-reviewed studies were retained for qualitative synthesis. These spanned virtual reality, music, art, sports, and rehabilitation interventions. The goal was not quantitative aggregation or meta-analysis, but rather conceptual integration of convergent findings to inform the proposed framework of Flow-Induced Analgesia (FIA).

Results

Defining Flow

The concept of *flow* was first introduced by Mihaly Csikszentmihalyi in the 1970s as a psychological state of optimal experience in which individuals become fully absorbed in a challenging but intrinsically rewarding activity.[8,27] Flow represents an integration of cognitive, emotional, and motivational processes that creates a sense of effortless concentration, deep engagement, and enjoyment. Individuals in flow often report a distorted sense of time, diminished awareness of external distractions, and a merging of action and awareness.[28] Unlike passive distraction, flow requires active engagement, balancing the demands of the task with the individual's perceived skill level.

Core Characteristics of Flow

Csikszentmihalyi identified nine dimensions of the flow experience: (1) a balance between challenge and skill, (2) merging of action and awareness, (3) clear goals, (4) unambiguous feedback, (5) intense concentration on the task, (6) a sense of control over actions, (7) loss of self-consciousness, (8) altered sense of time, and (9) the autotelic nature of the experience, meaning it is intrinsically rewarding.[8,29] These dimensions collectively define flow as more than distraction; it is a holistic state of optimal attention and motivation.

Assessment of Flow

Several psychometric tools have been developed to measure flow. The Flow State Scale (FSS) and the Dispositional Flow Scale (DFS) are among the most widely used instruments, validated across sports, education, and occupational contexts.[30,31] The FSS captures state-level flow during a specific activity, whereas the DFS measures the trait-like propensity to experience flow. Other measures include the Experience Sampling Method (ESM), which captures momentary experiences of flow in naturalistic settings.[32] Although these instruments have not yet been widely applied in clinical pain populations, they provide potential tools for future research.

Neurocognitive Correlates of Flow

Neuroimaging studies suggest that flow is characterized by a unique neural profile. Functional MRI investigations demonstrate suppression of the DMN, a system associated with self-referential processing and rumination, during flow states.[14,15] This "hypofrontality" hypothesis suggests reduced activity in medial prefrontal regions and enhanced efficiency in attention and motor networks.[33] At the same time, dopaminergic reward pathways, including the striatum and ventral tegmental area, show increased activity, consistent with the intrinsic reward of flow.[17,34] Importantly, these networks overlap with known pain modulatory circuits, including descending analgesia pathways and salience networks.[16] Thus, the neurobiology of flow provides a plausible mechanism for its potential role in pain modulation.

Flow vs Distraction and Mindfulness

It is critical to distinguish flow from other attentional strategies in pain management. Distraction refers to shifting attention away from painful stimuli, often through external tasks or stimuli (eg, music, VR). While distraction reduces pain temporarily, it is often passive and lacks the sustained, intrinsic engagement of flow.[35] Mindfulness, on the other hand, involves nonjudgmental awareness of present-moment experiences, including pain itself, aiming to alter the relationship with discomfort rather than suppress perception.[36] Flow lies conceptually between these constructs: like distraction, it diverts attention from pain, but unlike distraction, it relies on active engagement; like mindfulness, it fosters deep concentration, but it does so in the service of task immersion rather than open monitoring. These distinctions between flow, distraction, and mindfulness are summarized in Table 1.

Table 1 Key Differences and Predicted Neural Correlates Among Flow, Distraction, and Mindfulness in the Context of Pain

Dimension	Flow	Distraction	Mindfulness	Predicted Neural Correlates
Attentional focus	Intense absorption in meaningful activity	Shift of attention away from pain	Open, non-judgmental awareness of sensations	dlPFC (top–down attention), parietal cortex
Goal orientation	Balance between challenge and skill	Task unrelated to intrinsic goals	Non-goal-directed awareness	Frontoparietal control network
Reward system	Intrinsic reward, autotelic engagement	Minimal or extrinsic reward	None (acceptance-based)	Striatum, VTA, nucleus accumbens
Self-referential processing	Suppression of self-focus and rumination	No direct modulation	Enhanced interoceptive and self-awareness	DMN, mPFC, PCC
Affective tone	Positive affect, enjoyment	Neutral or variable	Non-reactive acceptance	vmPFC, ACC, amygdala
Clinical relevance	Sustained motivation, adherence, analgesia	Temporary distraction from pain	Improved acceptance, reduced distress	PAG–RVM (descending modulation)

Abbreviations: dlPFC, dorsolateral prefrontal cortex; ACC, anterior cingulate cortex; DMN, default mode network; VTA, ventral tegmental area; mPFC, medial prefrontal cortex; vmPFC, ventromedial prefrontal cortex; PAG, periaqueductal gray; RVM, rostral ventromedial medulla.

Clinical Relevance of Defining Flow

For pain medicine, clarifying the construct of flow is essential to avoid conflating it with mere distraction or relaxation. If flow can be reliably induced in clinical contexts (through adaptive VR, gamified rehabilitation, or arts-based interventions), it may offer a more powerful and sustainable means of reducing pain interference than transient distraction. Moreover, individuals differ in their dispositional capacity for flow; understanding these differences may help identify patients who could benefit most from flow-based interventions.

In summary, flow is a distinct psychological state marked by deep absorption, intrinsic motivation, and reward-driven attention. It is measurable, has clear neurocognitive signatures, and is conceptually distinct from other psychological interventions commonly used in pain medicine. This foundation provides the basis for exploring its role in pain perception and management.

Pain and Attention

Pain is not a purely sensory phenomenon but an integrated perceptual and cognitive-emotional experience. A key determinant of pain intensity and suffering is the way in which attention is allocated to painful stimuli. Contemporary cognitive-affective models emphasize that attention functions as both a gate and an amplifier of pain: selective focus on nociceptive input can heighten distress, whereas diversion of attention may reduce pain perception.[37,38]

The Pain Salience Network

Neuroimaging studies have consistently shown that pain perception involves activation of a distributed "pain matrix," including the insula, anterior cingulate cortex (ACC), thalamus, and prefrontal regions.[39,40] Within this system, the salience network—primarily the anterior insula and dorsal ACC—plays a central role in detecting and prioritizing salient stimuli, including pain.[41,42] When attention is captured by pain, the salience network shifts resources toward nociceptive processing, reinforcing the subjective experience of suffering. Hypervigilance, frequently observed in chronic pain patients, reflects a maladaptive bias toward constant monitoring of bodily sensations, mediated by this circuitry.[43]

Catastrophizing and Hypervigilance

Pain catastrophizing—defined as an exaggerated negative orientation toward pain stimuli—is a robust predictor of heightened pain intensity, disability, and poor treatment outcomes.[4,44] Catastrophizing is associated with hyperactivation of the salience network and diminished engagement of prefrontal regulatory regions, suggesting a failure to disengage from pain-related cues.[45,46] Hypervigilance compounds this effect: patients focus excessively on somatic sensations, increasing threat appraisal and reinforcing avoidance behaviors.[47,48] This attentional bias sustains the vicious cycle of pain, distress, and functional impairment.

Attentional Distraction and Analgesia

Given the role of attention, distraction has long been used as an adjunctive strategy for pain management. Experimental studies demonstrate that directing attention toward engaging cognitive tasks reduces both subjective pain reports and objective pain-related brain activity.[49,50] Virtual reality distraction, in particular, has shown robust analgesic effects by immersing patients in interactive environments, thereby consuming attentional resources otherwise devoted to nociception.[35,51] These findings highlight that pain is not simply the output of nociceptive pathways but is shaped by attentional competition.

Mindfulness as an Attentional Strategy

Mindfulness-based interventions represent another attentional approach, yet they differ fundamentally from distraction. Rather than diverting attention away from pain, mindfulness involves cultivating nonjudgmental awareness of present-moment experiences, including painful sensations.[52,53] Neuroimaging studies indicate that mindfulness reduces pain by modulating appraisal processes, decreasing activation in limbic structures, and enhancing prefrontal control.[54] While effective, mindfulness requires sustained training and may be challenging for some patients.

Positioning Flow Within Attentional Models of Pain

Flow offers a unique attentional state that lies between distraction and mindfulness. Like distraction, flow diverts attention away from pain, but it does so through deeply engaging, autotelic activities that sustain attention more effectively than passive stimuli. Unlike mindfulness, flow does not involve accepting pain; instead, it entails absorption in rewarding tasks that diminish awareness of discomfort. From a neural perspective, flow suppresses DMN activity, reducing self-focused rumination, while simultaneously engaging attentional and reward networks.[14,15] This dual action may counteract both catastrophizing and hypervigilance, creating conditions for analgesia.

Clinical Implications

Understanding pain through the lens of attention underscores the potential value of flow in clinical practice. If flow states can be reliably induced, they may provide stronger and more enduring pain relief than simple distraction and may be easier to adopt than mindfulness for some patients. Furthermore, individual differences in dispositional flow—the propensity to experience flow across activities—may explain variability in pain coping. Patients with higher flow proneness may naturally exhibit lower pain interference, suggesting a protective psychological trait worth leveraging in pain management programs.[55]

In sum, attention is central to the experience of pain. Maladaptive attentional patterns, such as catastrophizing and hypervigilance, amplify pain, whereas adaptive strategies that redirect or reframe attention can mitigate it. Flow represents a promising, though underexplored, attentional state that could be harnessed for therapeutic benefit in chronic pain.

Existing Evidence Linking Flow and Pain

Despite the theoretical fit between flow states and pain modulation, direct empirical studies are still limited. However, several strands of evidence from virtual reality, music, arts, physical activity, and rehabilitation indirectly support the analgesic potential of flow. These findings collectively suggest that immersive, autotelic engagement can reliably reduce pain perception and improve coping.

Virtual Reality and Immersive Technologies

Perhaps the most robust body of evidence comes from the use of virtual reality for pain management. Early foundational work also demonstrated analgesic effects of immersive VR environments.[56] VR environments, particularly those designed to be interactive and adaptive, often induce flow-like experiences by balancing task demands with user skill and providing immediate feedback. Early clinical trials in burn patients demonstrated that VR distraction substantially reduced pain during wound care and physical therapy, with reductions in reported pain intensity of up to 50%.[51,57] Functional imaging confirmed that VR analgesia is associated with decreased activation of pain-related regions in the insula and anterior cingulate cortex.[58]

In chronic pain, immersive VR interventions have demonstrated significant improvements in pain intensity and interference. A randomized controlled trial in patients with fibromyalgia found that gamified VR environments, which foster flow by providing adaptive challenges, yielded greater pain reduction than noninteractive 2D control conditions.[59] Meta-analyses support VR as a promising adjunctive treatment for both acute and chronic pain.[60] Importantly, studies report that higher engagement and perceived immersion correlate with stronger analgesic outcomes, suggesting that flow may be the mediating factor.[61]

Music and Flow-Induced Analgesia

Music is another domain where flow-like immersion contributes to analgesic effects. Experimental studies demonstrate that engaging with music, particularly when it induces emotional absorption and active participation (eg, playing an instrument, singing), reduces pain ratings.[21,62] Neuroimaging reveals that music-induced analgesia engages reward and emotion-processing circuits, overlapping with flow-related pathways.[63,64] A systematic review concluded that music can reduce both acute and chronic pain, particularly when patients actively choose or engage with the music, consistent with the autotelic quality of flow.[65]

In clinical settings, individualized music therapy has been associated with improved pain tolerance and reduced opioid use among surgical patients.[66] Moreover, dispositional traits related to flow, such as absorption and openness to experience, predict stronger analgesic responses to music.[67] This suggests that music may serve as a natural and accessible avenue for inducing flow-induced analgesia.

Artistic and Creative Activities

Beyond music, artistic engagement—including painting, dance, and creative writing—can evoke flow experiences that reduce perceived pain. Pilot studies in oncology and chronic pain populations indicate that arts-based interventions improve pain outcomes, emotional well-being, and quality of life.[68,69] Participants often describe losing track of time, feeling absorbed in the activity, and experiencing reduced awareness of pain. These subjective reports align with the phenomenology of flow and suggest that creative engagement may operate as a flow-based analgesic mechanism.[70]

Physical Activity, Exercise, and Sports

Exercise is an established nonpharmacological intervention for chronic pain, but its effectiveness may be mediated by psychological factors. It is possible that engaging in flow state during physical activity could be used as a pain management tool, but currently this aspect warrants further study. Athletes frequently report reduced pain perception during flow states in training or competition.[71] In rehabilitation contexts, designing exercise programs that optimize flow (eg, gradual skill challenges, clear goals, real-time feedback) enhances motivation, decreases perceived exertion, and may reduce musculoskeletal pain.[23,72]

Clinical Rehabilitation and Flow

In chronic pain rehabilitation, maintaining patient engagement is a critical challenge. Flow may serve as a motivational mechanism that improves adherence and outcomes. Studies in physiotherapy indicate that when exercises are structured to be engaging and skill-balanced, better results of reducing pain are reached.[73] Gamified rehabilitation platforms explicitly aim to induce flow by providing adaptive challenges and immediate feedback. Early data suggest that patients experience greater improvements in functional capacity and reduced pain interference compared to standard physiotherapy.[74,75]

Additionally, dyspositional flow and other psychological mechanisms such as intrinsic motivation can likely be correlated with resilience and coping in chronic pain populations.[76] Individuals with higher proneness to flow report lower pain interference, suggesting that flow may buffer against the negative impact of chronic pain. This aligns with broader literature indicating that flow supports psychological well-being and adaptive coping.[77]

Preliminary Clinical Evidence

Direct studies explicitly linking flow and pain are still sparse. One small-scale study assessed flow during music therapy sessions in fibromyalgia patients and found that higher flow scores correlated with greater reductions in pain interference and catastrophizing.[67] Another pilot intervention incorporated flow-inducing tasks into cognitive-behavioral therapy for chronic pain, reporting enhanced treatment adherence and satisfaction, though pain reduction outcomes were preliminary.[78] These early findings underscore both the feasibility and promise of flow-based interventions, while highlighting the need for rigorous randomized trials.

Integrating the Evidence

The reviewed studies varied widely in design and population, encompassing experimental pain paradigms, chronic pain cohorts (eg, fibromyalgia, rehabilitation), and arts- or VR-based interventions, without standardized outcome reporting. Taken together, the literature suggests that immersive, engaging activities—VR, music, art, sports, and rehabilitation exercises—can significantly reduce pain perception and interference. While most studies attribute these effects to distraction or emotional modulation, the phenomenological overlap with flow is striking. Activities that maximize challenge-skill balance, provide immediate feedback, and are intrinsically rewarding consistently yield stronger analgesic effects. Moreover, neuroimaging evidence from VR and music studies demonstrates engagement of attentional, reward, and salience networks that overlap with flow correlates.

Although the term “flow” is rarely used in pain research, the convergence of findings across modalities supports the hypothesis that flow is an unrecognized mechanism underlying many nonpharmacological pain interventions. This provides a strong rationale for explicitly testing flow as a mediating factor and for developing clinical protocols that deliberately induce flow states.

Flow-Induced Analgesia: A Conceptual Framework

The converging evidence from psychology, neuroscience, and pain research supports the idea that *flow* may act as a distinct mechanism of pain modulation. To move beyond correlational findings, it is essential to articulate a conceptual framework—flow-induced analgesia—that explains how flow states can alter pain perception and interference. This framework integrates cognitive-attentional, affective, motivational, and neurobiological processes, and it generates testable predictions for clinical research. The overall framework of flow-induced analgesia is illustrated in Figure 1.

A multilevel mapping of psychological constructs and predicted neural signatures is presented in Supplementary Figure S1.

Core Proposition

Flow-induced analgesia proposes that when individuals enter a flow state—marked by full absorption in a task, balance of challenge and skill, clear goals, and intrinsic reward—their neural and psychological resources shift away from pain processing toward task engagement. This shift suppresses maladaptive processes such as catastrophizing

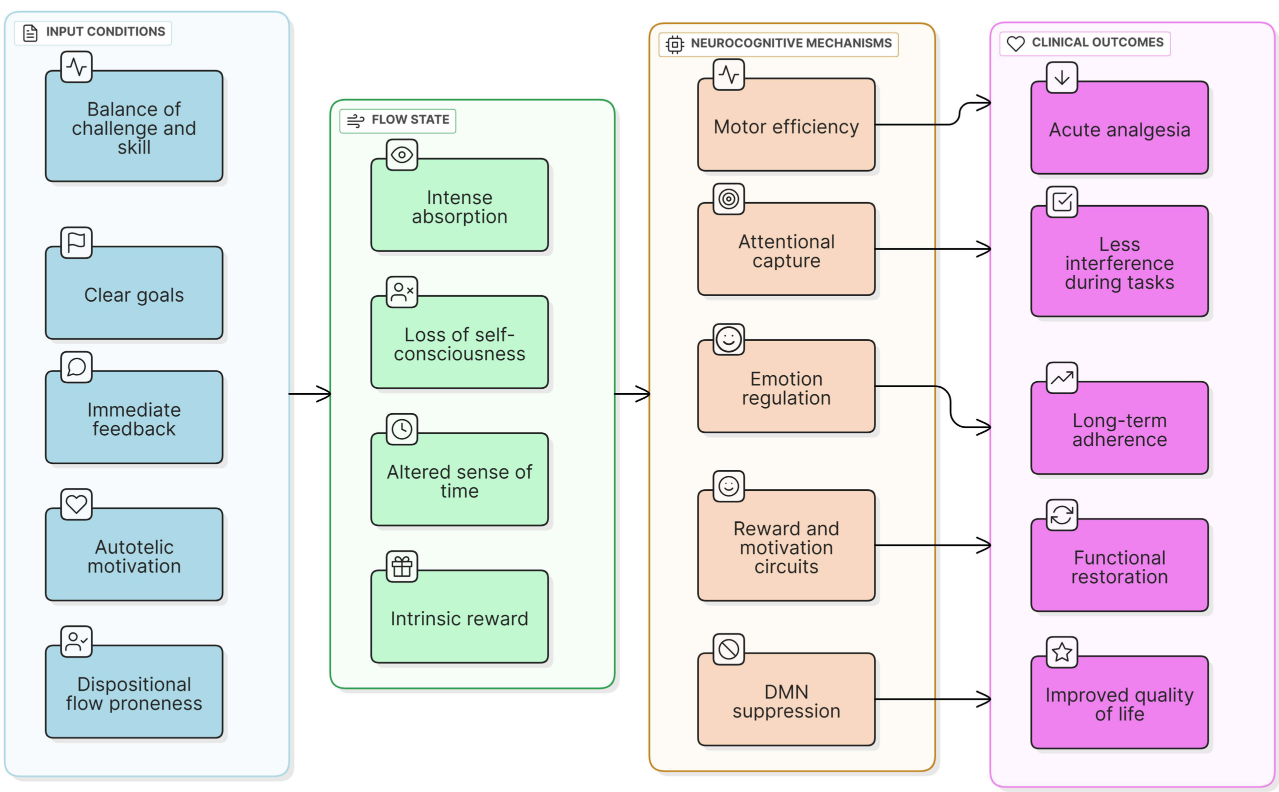

Figure 1 Conceptual framework of Flow-Induced Analgesia.
Notes: The schematic shows how input conditions (challenge–skill balance, clear goals, immediate feedback, autotelic motivation, and dispositional flow proneness) facilitate entry into a flow state characterized by absorption, intrinsic reward, loss of self-consciousness, and altered sense of time. These flow components influence neurocognitive mechanisms such as attentional capture, emotion regulation, reward/motivation processes, motor efficiency, and suppression of the DMN. These processes contribute to clinical outcomes including acute analgesia, reduced pain interference, improved adherence, functional restoration, and enhanced quality of life.
Abbreviation: DMN, default mode network.

Table 2 Proposed Mechanisms of Flow-Induced Analgesia

Mechanism	Neural/Psychological Basis	Clinical Implication
Attentional capture	Consumption of cognitive resources, reduced salience network activity	Less catastrophizing and hypervigilance
DMN suppression	Reduced self-referential rumination	Breaks cycle of negative pain focus
Reward/motivation activation	Dopaminergic and opioid pathways	Intrinsic reinforcement of therapy
Emotion regulation	Positive affect, reduced HPA axis stress	Improved resilience and QoL
Motor efficiency	Automaticity in movement, reduced fear-avoidance	Better adherence to exercise therapy

Abbreviations: HPA, hypothalamic-pituitary-adrenal axis; QoL, quality of life.

and hypervigilance, activates descending pain inhibitory systems, and produces both acute reductions in pain perception and longer-term improvements in pain coping. The core mechanisms proposed for flow-induced analgesia are presented in Table 2.

Mechanistic Pathways

Attentional Capture

Flow requires intense focus on a meaningful task. By monopolizing attentional capacity, flow reduces the cognitive resources available for nociceptive processing, similar to distraction but more sustained and self-reinforcing.[49,50] Unlike passive distraction, flow sustains attention without external reminders, due to intrinsic reward.

Suppression of Self-Referential Processing

Flow is characterized by diminished activity of the DMN, which is implicated in rumination and self-focused worry.[14,79] In chronic pain, DMN hyperconnectivity has been linked to pain persistence and catastrophizing.[80] By down-regulating DMN activity, flow may directly counteract maladaptive self-referential processes that amplify pain.

Reward and Motivation Circuits

Flow activates dopaminergic pathways in the striatum and ventral tegmental area, which overlap with networks involved in placebo analgesia and descending modulation of pain.[34,81] This provides a neurochemical basis for the analgesic effects of flow: intrinsic reward may recruit endogenous opioid and dopamine systems to dampen nociceptive signaling. These mechanisms are likely to operate interactively rather than additively, with attentional absorption enhancing reward engagement, and reward-driven motivation in turn reinforcing sustained attention and descending inhibitory control. This reciprocal interaction may underlie the integrative and self-reinforcing nature of FIA.

Emotion Regulation

Flow elicits positive affect and reduces stress responses, including hypothalamic-pituitary-adrenal (HPA) axis activation.[82] Reduced stress reactivity has been associated with improved pain thresholds and better coping.[83] Thus, flow may indirectly relieve pain through emotion regulation.

Motor and Embodied Engagement

Many flow activities—exercise, dance, rehabilitation tasks—involve movement. Flow states facilitate smooth, automatic motor execution, which may reduce fear-avoidance and guarding behaviors common in chronic pain.[3,84] By encouraging efficient movement without overmonitoring, flow could restore functional mobility while reducing pain interference.

In order to conceptually integrate the psychological constructs of flow with their corresponding neural correlations and mechanisms of analgesia, we developed a summary table illustrating these relationships. These associations are presented in Table 3, which cross-walks key psychological dimensions of flow (attention, motivation, reward, embodiment) with their predicted neural signatures and potential analgesic effects. The neurobiological pathways of flow-induced analgesia are represented in Figure 2.

Table 3 Cross-Walk of Core Flow Constructs and Predicted Neural Signatures

Flow Construct	Predicted Neural Correlates	Potential Analgesic Mechanism
Attentional absorption	dlPFC, parietal cortex	Top–down attentional control, reduced pain salience
Intrinsic motivation/reward	Striatum, VTA, nucleus accumbens	Dopaminergic reward engagement, activation of descending modulatory systems
Emotion regulation/positive affect	vmPFC, amygdala, ACC	Reduced limbic reactivity, improved stress coping
Suppression of self-referential processing	DMN, mPFC, PCC	Decreased rumination and catastrophizing
Embodiment and motor engagement	Cerebellum, basal ganglia, sensorimotor cortex	Enhanced movement automaticity, reduced fear-avoidance

Abbreviations: dlPFC, dorsolateral prefrontal cortex; ACC, anterior cingulate cortex; mPFC, medial prefrontal cortex; vmPFC, ventromedial prefrontal cortex; DMN, default mode network; VTA, ventral tegmental area; PCC, posterior cingulate cortex.

Among the experimentally verified forms of endogenous analgesia and hypoalgesia, approximately ten mechanisms have been consistently described in the literature. A summary of experimentally established forms of endogenous analgesia and their tentative relationship to FIA is presented in Table 4.

These include exercise-induced hypoalgesia (EIH),[85] stress-induced analgesia (SIA),[86] conditioned pain modulation (CPM),[87] placebo analgesia,[88] distraction-induced analgesia,[89] mindfulness- and meditation-induced analgesia,[90] hypnosis-induced analgesia,[91] music-induced analgesia,[92] conditioned (learned) analgesia, and endocannabinoid analgesia.[93]

Several of these mechanisms may partially overlap with processes proposed under the concept of Flow-Induced Analgesia (FIA) — particularly EIH, placebo, distraction, mindfulness, and music-induced analgesia.

These systems have been shown to involve dopaminergic, opioidergic, and endocannabinoid modulation within the PAG, RVM, and prefrontal–striatal circuits that are also hypothesized to participate in flow-related pain modulation.

However, direct evidence linking FIA to these mechanisms remains limited, and the degree of convergence among them has yet to be empirically determined.

FIA appears distinct in its self-generated, intrinsically rewarding attentional engagement, potentially integrating motivational, cognitive, and affective modulation within a unified biopsychosocial framework.

Importantly, the psychophysiological intensity of the flow state—combining focused attention, autonomic arousal, and intrinsic reward—may produce analgesic effects comparable in magnitude to stress-induced analgesia (SIA).

This hypothesis remains tentative, given that both states are thought to recruit dopaminergic–opioidergic descending control and engage the PAG–RVM system.

Unlike SIA, however, flow represents a self-regulated and rewarding form of activation rather than a reaction to threat, and future studies are required to determine whether its analgesic magnitude can approximate that of stress-related mechanisms under controlled conditions.

Acute vs Long-Term Effects

Flow-induced analgesia can be conceptualized as having two layers:

- Acute effects: Immediate reduction of pain perception during the flow state, driven by attentional capture and reward engagement. Patients often report being "less aware" of pain while deeply absorbed.
- Cumulative effects: Repeated engagement in flow-inducing activities may recalibrate attentional and emotional networks, reduce catastrophizing, and promote resilience. Over time, this may be able to diminish overall pain interference, improve quality of life, and enhance adherence to therapy.[76,77]

Testable Hypotheses

From this framework, several empirically testable predictions arise:

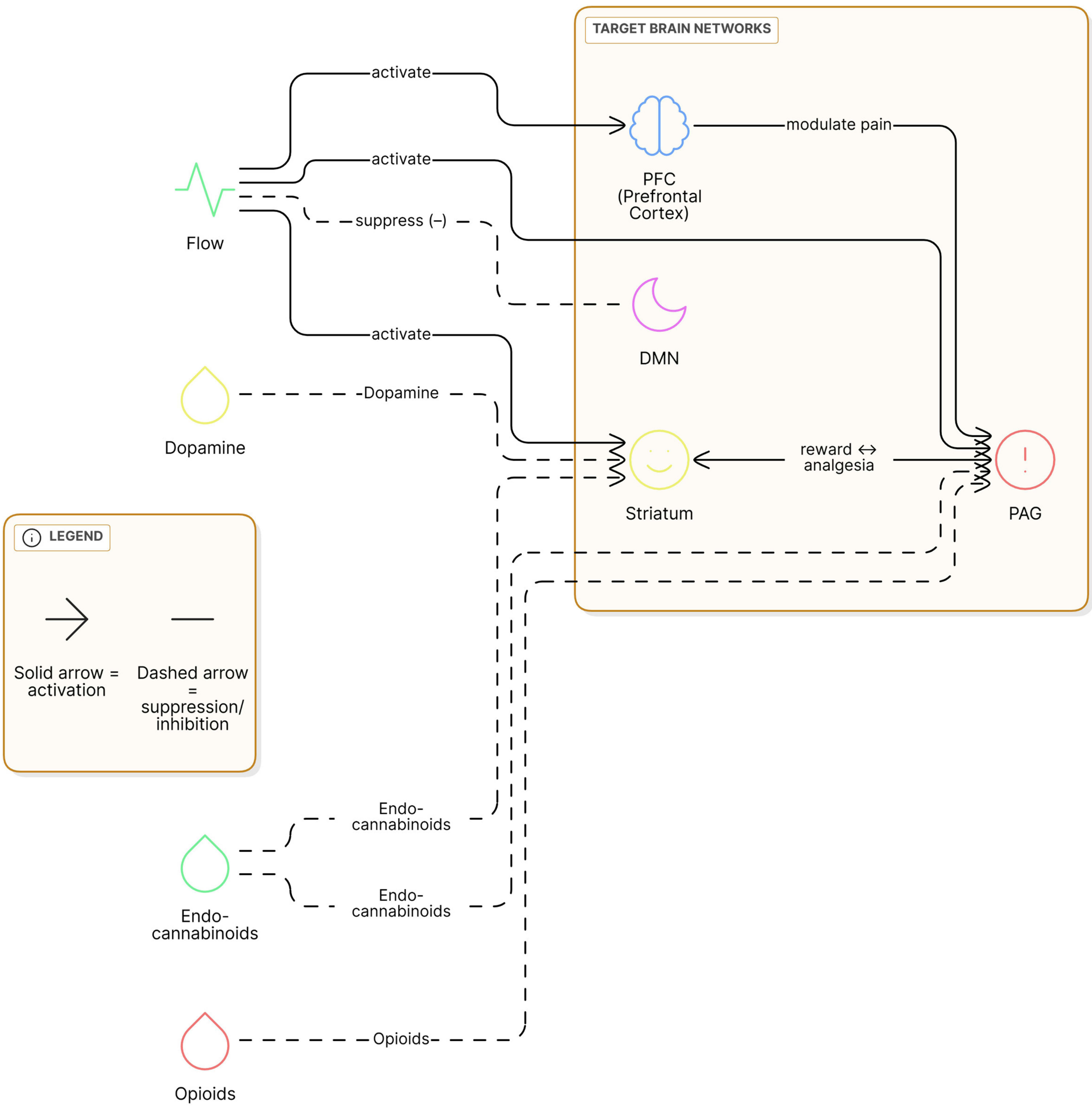

Figure 2 Proposed Neurobiological Model of Flow-Induced Analgesia (FIA).

Notes: The schematic depicts hypothesized engagement of distributed brain networks involved in pain modulation during flow states. Flow (green) is associated with enhanced activity in the prefrontal cortex (PFC, blue), supporting top-down attentional control, and in the striatum (yellow), reflecting dopaminergic reward processing. The striatum interacts with the periaqueductal gray (PAG, red), which participates in descending analgesic pathways mediated by opioidergic and possibly endocannabinoid systems. Concurrently, flow is linked to suppression of the default mode network (DMN, purple), consistent with reduced self-referential processing. Together, these elements outline a multilevel model integrating attention, motivation, reward, and descending modulation in flow-related analgesia.

Abbreviations: PFC, prefrontal cortex; PAG, periaqueductal gray; DMN, default mode network.

- H1: Flow-inducing tasks produce greater reductions in pain intensity than non-flow engaging distraction tasks of equal sensory load.[79]
- H2: The magnitude of pain reduction correlates with validated flow measures (eg, Flow State Scale scores).[29,30]
- H3: Suppression of DMN activity mediates the relationship between flow and analgesia, measurable with fMRI (functional magnetic resonance imaging) or EEG (electroencephalography).[14]

Table 4 Experimentally Established Forms of Endogenous Analgesia and Their Tentative Relationship to Flow-Induced Analgesia (FIA)

Type of Endogenous Analgesia/Hypoalgesia	Primary Trigger/Context	Main Neurochemical Mediators	Key Neural Pathways/Structures	Tentative Relationship to Flow-Induced Analgesia (FIA)
Exercise-Induced Hypoalgesia (EIH)	Acute aerobic or resistance exercise	β-Endorphins, endocannabinoids, serotonin	PAG–RVM descending pathways, motor cortex, spinal inhibitory interneurons	Overlap via motor engagement, endorphin/endocannabinoid release, and PAG–RVM activation during active movement
Stress-Induced Analgesia (SIA)	Acute or moderate stress exposure	Endorphins, noradrenaline, cortisol	Hypothalamus, amygdala, PAG	Partial overlap through sympathetic arousal and opioidergic descending control; differs by threat-driven activation
Conditioned Pain Modulation (CPM)	"Pain inhibits pain" paradigm (heterotopic conditioning)	Endorphins, noradrenaline, serotonin	Brainstem (PAG–RVM–spinal circuits)	Shares descending inhibitory architecture but lacks motivational/ reward engagement seen in flow
Placebo Analgesia	Expectancy, conditioning, therapeutic context	Endorphins, dopamine	PFC, ACC, PAG, striatum	Conceptual overlap via reward and expectancy-related dopaminergic–opioidergic pathways
Distraction-Induced Analgesia	Cognitive or sensory attentional task	Dopamine, acetylcholine	dlPFC, parietal cortex, thalamus	Shares attentional gating and top-down modulation; flow provides sustained intrinsic engagement beyond distraction
Mindfulness/Meditation-Induced Analgesia	Focused attention or open monitoring	Serotonin, endorphins, GABA	ACC, insula, DMN modulation	Shares DMN suppression and prefrontal regulation; differs by goal-directed, task-related focus in flow
Hypnosis-Induced Analgesia	Hypnotic absorption and suggestion	Endorphins, acetylcholine	PFC, ACC, insula	Parallel attentional absorption but externally induced and suggestion-dependent
Music-Induced Analgesia (MIA)	Active or receptive engagement with music	Dopamine, endorphins, oxytocin	Striatum, PAG, limbic system	Overlaps via reward and affective immersion; flow extends to motor and attentional domains
Conditioned (Learned) Analgesia	Pavlovian associative learning	Endorphins, dopamine	PFC, PAG	Shares top-down expectation control; differs by learned cue dependency
Endo-cannabinoid Analgesia	Activation of CB1/CB2 receptors by endogenous ligands	Anandamide, 2-AG	PAG, amygdala, spinal dorsal horn	Biochemical overlap through endocannabinoid signaling implicated in flow states
Flow-Induced Analgesia (FIA)	Deep attentional absorption in skill–challenge balance	Dopamine, endorphins, endocannabinoids	PFC, striatum, PAG, DMN suppression	Integrative mechanism combining attention, motivation, reward, and descending modulation; overlaps multiple domains

Abbreviations: ACC, anterior cingulate cortex; CB1/CB2, cannabinoid receptors 1 and 2; CPM, conditioned pain modulation; DMN, default mode network; dlPFC, dorsolateral prefrontal cortex; EIH, exercise-induced hypoalgesia; FIA, Flow-Induced Analgesia; GABA, gamma-aminobutyric acid; MIA, music-induced analgesia; PAG, periaqueductal gray; PFC, prefrontal cortex; RVM, rostral ventromedial medulla; SIA, stress-induced analgesia; 2-AG, 2-arachidonoylglycerol.

- H4: Individuals with higher dispositional flow proneness show lower pain interference and stronger analgesic responses to flow-based interventions.[55]
- H5: Pharmacological modulation of dopamine or opioid systems alters the analgesic efficacy of flow, paralleling findings in placebo research.[81,94]

Clinical Relevance

The framework of flow-induced analgesia emphasizes clinical utility. Pain rehabilitation often struggles with adherence; patients discontinue therapies due to low motivation or high discomfort. By incorporating flow-inducing design—adaptive difficulty, clear goals, immediate feedback, intrinsic reward—rehabilitation programs can transform repetitive exercises into engaging activities. This is evident in VR therapy, gamified rehabilitation, and arts-based programs.[74,75]

Moreover, flow-induced interventions may be especially useful in populations where pharmacological strategies have limited efficacy (eg, fibromyalgia, neuropathic pain) or where medication burden is high. If validated, flow could become a low-cost, side-effect-free adjunct to multimodal pain management.

Limitations and Boundaries

Current research on flow is limited by methodological heterogeneity and small-scale designs. Different instruments are used to assess flow (eg, FSS, FSS-2, DFS, Flow Short Scale), and most neuroimaging and experimental studies are based on small samples, limiting generalizability and reproducibility. In addition, paradigms used to induce flow vary widely—from virtual reality and music to motor and cognitive tasks—making direct comparison across studies difficult. Future research should aim to standardize flow assessment and employ adequately powered designs to strengthen methodological rigor.

Available evidence remains largely correlational, and few studies differentiate between acute and chronic pain populations or specific clinical subgroups such as fibromyalgia and post-surgical pain. The framework acknowledges that not all patients can easily enter flow. Factors such as depression, cognitive impairment, or lack of engaging activities may hinder flow induction. Flow may be less effective in acute, high-intensity pain where attentional capture by nociception is overwhelming. Additionally, excessive immersion (eg, gaming addiction) represents a potential risk. Therefore, flow-based interventions must be carefully tailored, safe, and patient-centered.[95] Future work should address practical parameters such as cost, accessibility, therapist training, and optimal session "dosing" (duration, frequency, and intensity) to enable safe and scalable implementation.

FIA may serve as a mechanistic target for non-pharmacological pain modulation. Emerging artificial-intelligence-driven tools could support adaptive personalization, robust evaluation, and ethical governance frameworks required to translate flow-based interventions into safe, scalable, and clinically credible pain-management solutions.[96]

Summary

Flow-induced analgesia posits that flow is not merely a pleasant byproduct of engaging activities but a distinct analgesic state with identifiable mechanisms. By integrating attention, motivation, reward, and emotion regulation, flow may represent a natural analgesic pathway that can be deliberately harnessed in clinical practice. This framework provides a foundation for systematic research and the development of flow-based interventions in pain medicine. An integrative overview of flow components and their neurobiological interactions with pain systems is outlined in Table 5.

Clinical Applications

Translating the concept of *flow-induced analgesia* into practice requires careful consideration of clinical contexts, delivery methods, and patient characteristics. Although empirical research is still emerging, several avenues illustrate how flow can be deliberately harnessed in pain medicine.

Virtual Reality and Gamified Interventions

VR is the most direct application of flow principles to pain management. Modern VR platforms incorporate adaptive difficulty, clear goals, and immediate feedback—elements known to foster flow.[60,61] Patients immersed in such

Table 5 Flow-Induced Analgesia and Pain Neurobiology: Integrative Mechanisms

Flow Component	Neural Correlates (Flow)	Pain System Interaction	Expected Analgesic Effect
Attentional absorption	Dorsolateral prefrontal cortex (dlPFC), parietal cortex → ↑ task-positive network	Competes with salience network (insula, ACC) for attentional resources	↓ Pain salience, ↓ catastrophizing
Loss of self-consciousness (reduced rumination)	↓ Default Mode Network (mPFC, PCC, precuneus)	Chronic pain = DMN hyperconnectivity → linked to catastrophizing	↓ Pain-related self-focus, ↓ negative appraisal
Intrinsic reward/ autotelic motivation	Ventral striatum, nucleus accumbens, VTA (dopamine release)	Interacts with descending pain modulatory system via PAG–RVM	↑ Dopamine, ↑ endogenous opioids → ↓ nociceptive transmission
Positive affect and emotion regulation	Ventromedial PFC, amygdala, ACC → improved affect regulation	Chronic pain = ↑ limbic reactivity, stress sensitization (HPA axis)	↓ Cortisol, ↓ affective amplification of pain, ↑ resilience
Motor automaticity and embodiment	Basal ganglia, cerebellum → smooth automatic motor control	Chronic pain = motor hypervigilance, fear-avoidance, ↑ muscle guarding	↓ Guarding, ↑ efficient movement, ↓ peripheral nociceptive input
Altered sense of time (flow timelessness)	Insular cortex (integration of interoceptive signals), basal ganglia	Pain perception heavily depends on interoception and time awareness	↓ Pain intensity through temporal distortion
Sustained engagement/ adherence	Frontoparietal control network (sustained goal orientation)	Chronic pain patients often disengage due to fatigue and avoidance	↑ Therapy adherence, long-term ↓ disability

Notes: Symbols, ↑ = increased activity or facilitation; ↓ = decreased activity or inhibition; → = neutral interaction.
Abbreviations: dlPFC, dorsolateral prefrontal cortex; ACC, anterior cingulate cortex; mPFC, medial prefrontal cortex; PCC, posterior cingulate cortex; DMN, default mode network; VTA, ventral tegmental area; PAG, periaqueductal gray; RVM, rostral ventromedial medulla; PFC, prefrontal cortex; HPA, hypothalamic-pituitary-adrenal axis.

environments often report "losing track of time" and experiencing significant reductions in pain intensity. A recent meta-analysis confirmed that interactive VR interventions are superior to passive 2D distraction for both acute and chronic pain.[60] Beyond short-term analgesia, VR-based rehabilitation games encourage repeated engagement, potentially leading to long-term improvements in functional capacity and quality of life.[75]

Gamification in non-VR settings also holds promise. Rehabilitation programs that transform repetitive exercises into adaptive, rewarding challenges can promote adherence and potentially enhance analgesic outcomes.[74,97] As well as biofeedback-assisted physical therapy that could be combined with gamified tasks would likely show to improve motivation and reduce pain interference in patients with musculoskeletal disorders.[98]

Music and Arts-Based Therapies

Music therapy offers a widely accessible modality to induce flow in clinical populations. Active engagement—singing, playing an instrument, or interactive listening—enhances immersion compared with passive music exposure.[21] Flow-inducing music therapy has been associated with reduced opioid consumption in surgical patients and improved quality of life in individuals with chronic pain.[66] Similarly, arts-based interventions (painting, dance, creative writing) have demonstrated analgesic benefits, often described by patients in terms of absorption, timelessness, and reduced self-awareness—hallmarks of flow.[68,69]

Integrating structured art or music sessions into pain clinics may provide low-cost, side-effect–free adjuncts to pharmacological treatments. Importantly, patients frequently report high satisfaction with such interventions, which may strengthen therapeutic alliance and adherence.[70]

Exercise and Physiotherapy

Exercise is a cornerstone of chronic pain management, but adherence is often limited by pain-related fear, boredom, or lack of motivation. Designing physiotherapy sessions to promote flow may transform patient experience. Strategies include tailoring exercises to individual skill levels, providing clear goals, and integrating immediate feedback through digital platforms.[71,73] Studies indicate that patients experiencing flow during rehabilitation are more likely to persist, show improved functional outcomes, and report reduced pain interference.[99,100]

Moreover, movement-based therapies such as dance or tai chi naturally incorporate flow elements—rhythmic engagement, balance of challenge and skill, and intrinsic reward. These practices have demonstrated efficacy in fibromyalgia, osteoarthritis, and chronic back pain, though mechanisms are usually described in terms of "mind-body connection."[101] Reframing them as flow-inducing may help clarify their analgesic effects. Flow-based or gamified rehabilitation approaches should be considered complementary to, rather than superior to, standard physiotherapy until validated by controlled trials.

Patient Selection and Individual Differences

Not all patients are equally prone to experiencing flow. Dispositional flow—an individual's general tendency to enter flow states—varies widely and may influence treatment response.[76] Screening tools such as the Dispositional Flow Scale could help identify patients most likely to benefit from flow-based interventions. Conversely, individuals with severe depression, cognitive impairments, or low motivation may struggle to engage, requiring tailored approaches.

Clinicians must also recognize boundaries: flow-based strategies are not intended to replace pharmacological or interventional pain treatments but rather to complement them as part of a multimodal plan. Careful integration into interdisciplinary pain clinics is needed, ensuring that flow interventions are safe, engaging, and patient-centered.[5]

Implementation Considerations

To embed flow into clinical practice, several practical issues arise:

- Training and resources: Clinicians may require training in delivering flow-inducing interventions (eg, VR facilitation, music therapy).
- Accessibility: Cost and availability of VR equipment or arts programs may limit uptake, though low-cost gamified platforms are emerging.
- Evaluation: Routine use of validated flow scales during interventions could help monitor whether flow is achieved and link it with clinical outcomes.
- Ethical considerations: While promoting engagement is beneficial, clinicians must avoid over-immersion (eg, excessive gaming) or unrealistic expectations of analgesia.

Summary

Clinical translation of flow-induced analgesia is most promising in VR, gamified rehabilitation, music, arts-based therapies, and exercise programs. These modalities share common design principles that align with flow induction: balance between challenge and skill, clear goals, and immediate feedback. Early evidence suggests such interventions can reduce pain, enhance adherence, and improve quality of life. With further validation, flow-based strategies may become a valuable addition to multimodal pain management.

Future Research Directions

Although theoretical and indirect evidence supports the concept of FIA, rigorous empirical validation remains limited.

Future research should focus on developing standardized protocols, refining outcome measures, and clarifying mechanisms of action.

It will also be important to distinguish between trait flow (a dispositional tendency to experience flow) and state flow (a situational, task-induced experience), as these dimensions may differentially influence analgesic outcomes. Individuals high in trait flow may enter flow more easily and display stronger or more consistent flow-related analgesia.

In addition, future work should address current methodological constraints, such as heterogeneity in flow assessment tools and small sample sizes in neuroimaging studies, to improve reproducibility and generalizability.

Experimental designs should include pharmacologic probes (eg, dopaminergic or opioid antagonists), mediation-analysis frameworks, and adequate sample-size estimation to clarify causal pathways and validate the clinical magnitude of FIA.

Experimental and Clinical Trials

Randomized controlled trials (RCTs) are essential to establish causality. Pilot RCTs could compare flow-inducing interventions (eg, gamified VR, immersive music therapy) with active distraction and mindfulness controls. Key outcomes should include pain intensity, pain interference, adherence, and quality of life.[79] Neuroimaging and psycho-physiological measures (eg, fMRI, EEG, heart rate variability) can help identify mediating neural pathways.

Assessment and Measurement

Future studies should incorporate validated flow measures—such as the Flow State Scale (FSS) or Dispositional Flow Scale (DFS)—alongside pain outcomes. Linking subjective flow reports to analgesic effects will clarify whether flow is the active mechanism.[30] Ecological momentary assessment methods may capture real-time fluctuations in flow and pain in daily life, providing ecologically valid evidence.[32]

Mechanistic Probes

Pharmacological modulation (eg, dopaminergic or opioid antagonists) could be used experimentally to test whether flow analgesia depends on reward and endogenous opioid systems.[81] This would align flow research with placebo and expectancy paradigms in pain science, strengthening biological plausibility.

Population-Specific Applications

Flow-based interventions may be particularly beneficial in populations with limited pharmacological options, such as fibromyalgia, neuropathic pain, and adolescents with chronic pain. Tailoring interventions to age, cognitive capacity, and dispositional flow traits will be critical for generalizability.[5]

Integration into Multimodal Pain Management

Future clinical pathways could integrate flow-based programs into interdisciplinary pain clinics. Combining flow interventions with cognitive-behavioral therapy, physiotherapy, or pharmacological treatments may enhance adherence and improve overall outcomes. Implementation research will be needed to evaluate feasibility, scalability, and cost-effectiveness in real-world settings.[6] An integrative conceptual model of FIA is presented in Supplementary Figure S2.

Conclusion

Chronic pain remains one of the most pressing public-health challenges, and current treatments often provide only partial relief, leaving significant unmet needs in chronic pain care. Flow-based interventions—by integrating attentional, motivational, and emotional engagement—may help address these gaps through non-pharmacological, intrinsically motivating mechanisms.

Growing evidence underscores the importance of attentional, cognitive, and motivational processes in shaping pain perception. Within this context, the construct of flow—a state of deep absorption and intrinsic engagement—emerges as a promising yet underexplored mechanism.

This review synthesized evidence from psychology, neuroscience, and pain research to propose the framework of FIA. Flow differs from both distraction and mindfulness: it is sustained, intrinsically rewarding, and supported by distinctive neural patterns, including suppression of DMN activity and activation of reward and attentional circuits. Indirect evidence from virtual reality, music, arts, sports, and rehabilitation suggests that flow-like states consistently reduce pain perception and interference. Preliminary clinical findings indicate that higher flow proneness may buffer against pain-related distress.

At the mechanistic level, flow appears to engage dopaminergic and opioidergic pathways within the prefrontal–striatal circuitry and the PAG–RVM system, accompanied by suppression of the DMN.

These interconnected processes likely operate hierarchically—from attentional absorption to reward activation and, ultimately, descending modulation—illustrating the integrated neurobiological basis of FIA.

Although flow shares attentional and affective components with both distraction and mindfulness, it is conceptually distinct. Distraction analgesia involves a temporary shift of attention away from pain, either passively (eg, watching television) or actively (eg, playing a simple game), without sustained intrinsic motivation. Mindfulness-based pain modulation instead promotes non-judgmental awareness of bodily sensations and acceptance of pain. In contrast, flow represents active, self-reinforcing absorption, balancing challenge and skill, generating intrinsic reward, and engaging motivational and reward circuits. This distinction underlies the conceptual novelty of FIA as an integrative, adaptive process rather than a passive or acceptance-based strategy.

Clinically, flow-inducing interventions could enhance patient engagement, adherence, and quality of life across diverse pain populations. However, the current evidence base remains indirect, heterogeneous, and primarily correlational, and causal mechanisms underlying FIA have yet to be established. Flow-based interventions should therefore be viewed as complementary and exploratory within multimodal pain management rather than as established therapeutic options.

Future research should prioritize rigorous trials, integration of validated flow measures, and mechanistic probes—including pharmacologic and neuroimaging approaches—to determine biological pathways and clarify the scope of FIA. If confirmed, flow-based strategies may represent a valuable, nonpharmacological, low-risk, and intrinsically motivating addition to multimodal pain management, offering an innovative and accessible pathway to alleviate suffering and address unmet needs in chronic pain treatment.

Disclosure

The authors report no conflicts of interest in this work.

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