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Odor Plumes, Memory, and Decision Thresholds Together Transform Chemical Landscapes into Functional Behavioral Habitat for Insects

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ABSTRACT

Insects encounter odors as mixtures whose composition and intermittency change during transport, yet chemical landscapes are often interpreted as though signal presence alone defined behavioral relevance. This article develops a mechanistic framework in which external plume structure becomes functional behavioral habitat only after filtering through encounter timing, recent sensory history, learned experience, internal state, multimodal context, and action selection. Evidence from flies, mosquitoes, moths, pollination systems, and models supports temporal odor coding, history-dependent movement, learned revaluation, and state-dependent response. These findings do not establish one conserved neural threshold or universal navigation algorithm. The proposed synthesis therefore treats chemical habitat as relational and time-dependent. It generates testable cross-scale predictions while preserving taxonomic, life-stage, environmental, methodological, and laboratory-to-field boundaries.

Keywords: Odor plume, Insect olfaction, Temporal integration, Olfactory memory, Host-seeking behavior, Chemical ecology

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Introduction

Natural insect odorscapes are multicomponent scenes in which source emissions, background volatiles, transport, and temporal fluctuation jointly determine what reaches sensory organs [1]. Windborne pheromone and resource plumes are intermittent rather than smooth, so source-directed movement often depends on discrete encounters interpreted with directional information [2]. At broader scales, habitat odor can constrain host search before more specific host cues are available [3]. Chemical availability is therefore ecologically meaningful, but it does not explain why the same external field can become attractive, irrelevant, or inaccessible to different insects.

Time inside the organism is a second requirement. Learning studies in insect pollinators and herbivores show that prior experience can alter later resource choice [4]. Immediate sensory history, associative memory, and the motor expression of learned value are nevertheless different processes. Collapsing them into one generic “response to odor” hides where temporal information enters behavior.

This article proposes that chemical landscapes become functional behavioral habitat through conditional transformations. External structure determines encounter opportunities; sensory systems transform encounters into evidence; recent and learned history modify its meaning; physiological and multimodal context alter action

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relevance; and movement changes future sampling. The framework is intentionally cross-level, not a claim that insects share one conserved mechanism.

Materials and Methods

This synthesis organizes evidence by the level directly supported: external stimulus structure, peripheral or central sensory processing, individual movement, learning and memory, physiological modulation, population variation, and community association. This separation is necessary because odor identity alone is an incomplete stimulus description; concentration dynamics and timing change the information delivered to olfactory systems [5].

Multimodal evidence was retained where the biological task required it. In complex virtual environments, dipteran search depended on combinations of visual structure, airflow, and odor, with species-specific differences [6]. Such results justify treating wind and vision as parallel evidence streams rather than silently subsuming them under olfaction, while tethered virtual trajectories remain distinct from field dispersal.

Ecological-scale observations were likewise not upgraded into mechanism. Floral sensory traits, including scent, were associated with visitor structure in a Mediterranean pollination network [7]. Human-host preference in *Aedes aegypti* varied among African populations and covaried with climate, urbanization, and ancestry [8]. These are important community and population patterns, but neither establishes a universal causal pathway. The framework therefore preserves analytical level and transfer boundary at every inferential step.

Chemical landscapes as dynamic information fields

Chemical information can change after emission. Anthropogenic volatile pollutants can transform infochemicals, alter signal production, or add background compounds that change detectability during transport [9]. Source emission and sensory availability are therefore not synonymous.

Natural communities nevertheless contain structured chemical associations. Floral volatile profiles were associated with different visitor groups in a Mediterranean community [10]. Such patterning is compatible with sensory filtering but does not show that a particular volatile caused a network link. Community association cannot be reverse-engineered into individual mechanism.

Physical availability must also be separated from behavioral acceptance. Modeling of bumblebee search showed that olfactory and visual encounter domains can differ substantially [11]. Encounter, attraction, orientation, and successful localization are therefore distinct states. Chemical identity likewise lacks fixed valence: geosmin acts as an attractive cue in tested *A. aegypti* oviposition and larval contexts [12], but that result cannot be generalized across taxa, stages, or behavioral tasks. Chemical landscapes are thus dynamic information fields whose function depends on the organism and problem being solved.

Odor-plume structure and encounter probability

Intermittency makes odor appearance and loss mechanistically important. In walking *Drosophila*, odor onset promoted upwind-oriented movement whereas odor loss promoted local-search-like behavior [13]. The relevant input is therefore not simply concentration but the timing of encounter transitions relative to ongoing motion.

Across controlled navigation studies, recent odor history contributes to subsequent action rather than behavior being determined only by instantaneous concentration [13–15]. Complex-plume walking decisions were stochastic but biased by recent encounter timing, while flight analyses detected modest history dependence and only partial agreement with normative infotaxis. This supports short-term temporal integration without identifying one universal search algorithm.

Temporal structure is transformed already at early sensory stages. *Drosophila* receptor neurons and moth olfactory pathways can preserve or adapt to intermittent stimulus statistics [16–18]. These processes provide a substrate for retaining event timing, but they are sensory adaptation, not learned memory.

Fine timing can also change what is represented. *Drosophila* receptor-neuron spike timing provides rapid odor information [19], and small relative onset differences among mixture components can alter odor-object recognition behavior [20]. Exact timing values remain apparatus- and task-dependent rather than field thresholds. External plume statistics are further filtered by receptor nonlinearities that change which features are informative for a navigation objective [21].

Directional reference remains a separate information stream. Central *Drosophila* neurons encode wind direction through antennal mechanosensation [22], so odor evidence and airflow direction should remain analytically

distinct even when integrated during movement. Sampling is also partly active: flight aerodynamics can alter modeled odor flux reaching *Drosophila* antennae [23]. Movement can therefore change subsequent sensory input, creating a potential action-to-sampling feedback without demonstrating that insects optimize that feedback.

Memory and temporal integration

Short-term encounter history and learned memory solve different temporal problems. In adult female *A. aegypti*, aversive conditioning altered later responses to host-related odors, and disrupting dopamine signaling impaired learning [24]. This establishes experience-dependent revaluation in a defined mosquito context, not a general claim that host preference is learned.

Memory itself is not well represented as a single stored scalar. *Drosophila* mushroom-body learning is distributed across parallel plastic and output pathways [25]. Distinct mushroom-body outputs contribute differently to separate memory-guided behaviors [26], demonstrating that learned information and its behavioral expression can be separable.

Temporal integration can also be inhibitory. Prior odor exposure in *Drosophila* can produce a short-lived memory that conditionally suppresses expression of subsequent learning [27]. Earlier experience therefore need not accumulate monotonically toward stronger attraction or avoidance. During active *Drosophila* odor navigation, dopaminergic representations of movement also depend on behavioral context, and perturbation alters tracking strength [28]. This supports reciprocal coupling between current action and internal processing while cautioning against treating dopamine as a universal memory or decision variable.

The temporal mechanisms above answer different questions—what happened moments ago, what was learned previously, how earlier experience interferes with new learning, and how memory is expressed as action. A compact comparison is needed because merging them would falsely imply a single timescale or mechanism.

Table 1. Temporal integration stages that must remain distinct when odor history is translated into later insect behavior

Biological setting · Evidence	Interpretation	Boundary condition	Test implication · Evidential standing
Encounter-sequence history			
Walking and flying navigation **Recent odor-on/off timing biases later movement**	Immediate plume history can alter action before associative learning	Mainly controlled navigation studies	Manipulate intermittency at matched mean concentration Evidence-supported distinction
Peripheral temporal adaptation			
Drosophila and moth olfactory pathways **Gain and coding change with stimulus statistics**	Sensory history reshapes incoming evidence	Neural coding is not learned memory or navigation success	Couple dynamic stimuli to neural and behavioral measurement Evidence-supported distinction
Learned odor revaluation			
Adult female Aedes; Drosophila learning circuits **Conditioning changes later cue response**	Past experience can change future chemical value	Cue-, task-, sex-, and species-dependent	Compare naïve and trained insects under the same plume Evidence-supported distinction
Memory interference			
Adult Drosophila **Prior exposure can inhibit new learning expression**	Temporal integration can be non-additive	Timing and conditioning context matter	Vary pre-exposure interval before plume testing Evidence-supported distinction
Behavior-specific memory readout			
Drosophila mushroom-body outputs **Different outputs support different memory-guided behaviors**	Stored value and motor expression should remain separate	Circuit architecture cannot be assumed across orders	Test one learned cue across multiple actions Evidence-supported distinction
History-to-action integration state			
Cross-level synthesis **Joint presence of recent history, learned value, and current context**	Multiple temporal signals may jointly	Exact combined state has not been validated end-to-end	Factorially manipulate recent plume history and prior learning Proposed synthesis

	condition action readiness

Because immediate sensory history, associative learning, interference, and behavioral readout occupy different biological levels, they also require a visual architecture that shows interaction without implying identity. **Figure 1** places these temporal evidence states in separate regions and marks the cross-level links introduced by this article as proposed.

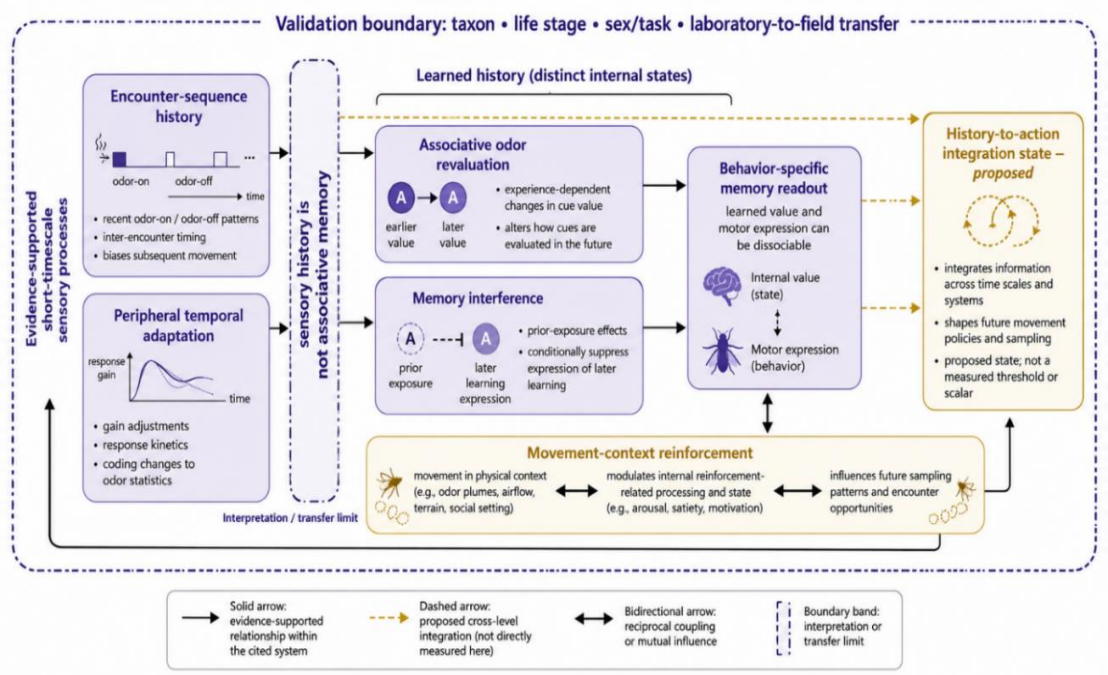


Figure 1. Temporal evidence states that make identical odor encounters behaviorally nonequivalent

Internal decision thresholds

"Decision threshold" is useful here only if it does not imply one conserved neural scalar. Mosquito host seeking demonstrates a functional gating principle: physiological state changes whether relevant host cues elicit search, with blood feeding and reproductive state suppressing and later permitting host seeking [29]. The threshold-like phenomenon is therefore a state-dependent change in response propensity, not necessarily a measurable universal number.

State can act early in the sensory pathway. In *Drosophila* larvae, feeding condition reconfigures early olfactory processing and can change the valence of specific odors through serotonergic circuitry [30]. Action relevance need not be applied only after a stable sensory representation has formed; the sensory evidence itself can depend on internal condition.

Response propensity also varies among individuals. In *A. aegypti*, age and sex are associated with changes in host-seeking responsiveness and antennal chemosensory-related gene expression around the onset of host seeking [31]. The molecular association is informative about maturation but does not establish a gene-level causal threshold. In male *Agrotis ipsilon*, age and prior pheromone exposure were associated with changes in behavioral and neuronal responsiveness and Neuroligin 1 expression, whereas a post-mating refractory condition showed a different correspondence [32]. Similar behavioral plasticity therefore need not imply one molecular mechanism.

A more literal evidence-accumulation process has been demonstrated in a defined *Drosophila* task. Opponent mushroom-body populations can integrate evidence for odor-intensity increases versus decreases in a manner compatible with race- or drift-diffusion-like competition [33]. This supports threshold-like accumulation in that task, not the claim that natural plume navigation generally uses the same computation.

Decision criteria can also be multimodal. In host-seeking *A. aegypti*, carbon dioxide altered visual steering and visual-neural responses, showing that chemical context can reweight another sensory modality before action [34]. The defensible synthesis is therefore functional rather than anatomically universal: temporally accumulated,

learned, physiological, and task-relevant evidence can condition whether an action becomes likely, but the responsible circuits and weighting rules may differ among taxa, stages, sexes, and behavioral problems.

The proposed framework consequently treats decision thresholds as a family of conditional action criteria. Motivational gating, state-dependent sensory reconfiguration, learned-value expression, and opponent evidence accumulation remain distinct mechanisms. Keeping them separate prevents a convenient abstract term from being mistaken for a conserved process and establishes the basis for asking how intermittent signals alter movement through space.

Movement consequences of signal intermittency

Odor-guided movement is not simply a trajectory toward increasing concentration. Intermittent plumes create sequences of encounters, losses, and directional opportunities that must be transformed into actions. In walking *Drosophila*, odor onset and loss generated different movement states, demonstrating that temporal transitions themselves can become behaviorally meaningful events [13]. Complex plume environments further showed that recent odor history can influence subsequent movement decisions rather than allowing instantaneous concentration alone to determine behavior [14, 15].

These results support a proposed distinction between chemical exposure and chemical evidence. Exposure describes the physical arrival of molecules at sensory organs; evidence describes the internally interpreted significance of those encounters. The same number of encounters may produce different movement outcomes depending on previous experience, current state, task demands, and competing sensory information.

Movement is also constrained by non-olfactory information. Wind direction provides a directional reference independent of odor identity, and central neural circuits in *Drosophila* encode airflow direction through antennal mechanosensation [22]. Similarly, host-seeking mosquitoes integrate carbon dioxide with visual information, demonstrating that chemical cues can modify another sensory channel before action [34]. Therefore, odor-guided movement should be considered a multimodal decision problem rather than an isolated olfactory reflex.

Active movement can also reshape future chemical sampling. Computational analyses of *Drosophila* flight showed that wing-generated airflow may influence odor flux reaching antennae [23]. This creates a possible feedback loop in which movement alters future sensory input. However, evidence for altered sampling does not demonstrate adaptive optimization of movement, and the ecological consequences of this feedback remain unresolved.

Variation among species and contexts further limits generalization. Virtual-reality search experiments reveal species-specific differences in how insects combine odor, airflow, and vision [6], while age- and sex-related differences in mosquito host-seeking demonstrate that identical chemical conditions may not generate identical movement states within a species [31]. Movement consequences therefore emerge from the interaction between plume structure and organismal state rather than from plume physics alone.

Chemical habitat as an emergent behavioral property

The concept of habitat is commonly linked to external environmental structure, but an insect does not encounter chemical space directly. It encounters transformed chemical information filtered through sensory systems, memory, internal condition, and movement capacity. This article proposes the term functional behavioral habitat for the subset of chemical space that becomes behaviorally meaningful for a particular insect under a particular state and task.

This proposed construct does not replace ecological descriptions of chemical landscapes. Habitat-scale odor research demonstrates that chemical environments influence interactions, while community studies show associations between floral chemistry and insect visitors [3, 10]. However, external chemical structure alone does not determine individual behavioral outcomes.

The same chemical environment may therefore contain multiple functional habitats. A cue associated with oviposition in female *Aedes* mosquitoes may not carry equivalent meaning for another insect, life stage, or behavioral context [12]. Likewise, learned aversion can alter responses to previously relevant host odors [24], and prior exposure can inhibit later learning expression rather than simply strengthening preference [27].

The proposed transformation from chemical landscape to functional behavioral habitat contains four separable analytical stages:

1. Physical availability: molecules are emitted and transported through space.
2. Sensory encounter: chemical and contextual information reaches sensory systems.

3. Internal interpretation: recent history, memory, physiological state, and multimodal context modify evidence.
4. Behavioral realization: movement changes occupancy and future encounters.

Only the final stage represents realized behavioral habitat, and even then the framework does not claim fitness benefit, ecological adaptation, or conservation relevance.

The recursive nature of this proposal is important. Movement alters future encounters through sampling conditions [23], while internal states alter the interpretation of sensory input [30]. However, these relationships occur at different biological levels and should not be merged into a single mechanism.

The framework therefore predicts conditional chemical habitats rather than fixed odor maps. Validation requires testing whether changes in plume statistics, memory, and internal state alter behavior in predictable ways across taxa and environments.

A prediction-and-test ledger is required because the proposed construct combines evidence from different biological levels. The following table distinguishes established evidence patterns from proposed extensions.

Table 2. Evidence boundaries and validation requirements for chemical landscapes becoming functional behavioral habitat

Chemical-habitat component	Dynamic chemical availability	Encounter interpretation	Memory-conditioned habitat value	State-dependent chemical meaning	Cross-level chemical habitat state	Population and community scaling
Evidence	Changing plume structure and signal timing	Odor onset/loss responses and encounter-history effects	Prior experience alters later odor responses	Feeding, reproductive, age, and sex effects	Joint interpretation of plume, memory, and state evidence	Variation in preferences and visitor associations
Research or test	Measure realistic plume dynamics during behavior	Test matched-mean but different intermittency patterns	Manipulate experience before naturalistic search	Combine state measurements with dynamic odor tests	Conduct factorial plume × history × state experiments	Link individual mechanisms with field interaction data
Interpretation or consequence · Boundary condition · Interpretive consequence	External chemical space is temporally variable Emission does not equal perception	Encounters can become action-relevant events Laboratory plumes do not fully reproduce natural landscapes	Functional habitat depends on history Learning is cue- and task-specific	Internal condition changes action probability State effects differ among taxa and stages	Behavioral habitat is relational rather than purely environmental Full construct has not been validated as one mechanism	Individual responses may contribute to larger patterns Association does not establish ecological consequence
Status · Biological context · Evidential standing · Biological setting	Evidence-supported basis Insects experiencing transported odors	Evidence-supported basis Dipteran navigation systems	Evidence-supported basis Mosquito and fly learning systems	Evidence-supported basis Mosquito and fly physiological states	Proposed synthesis Multiple insect systems	Proposed validation direction Aedes populations and pollination networks

The framework's central relationship structure is summarized visually in **Figure 2**.

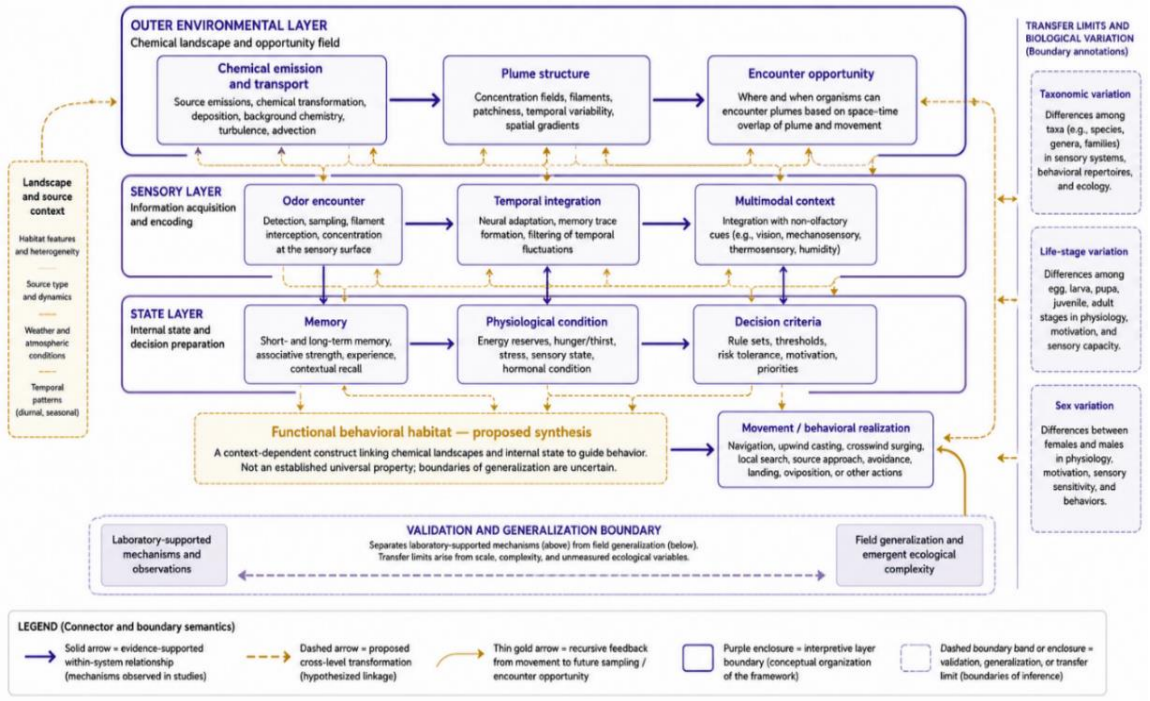


Figure 2. Conditions under which chemical landscapes acquire insect-specific behavioral meaning

Predictions across scales

The proposed framework generates predictions only by connecting mechanisms that have been independently observed. It does not claim that the complete architecture has already been experimentally validated.

First, if temporal structure contributes information beyond mean concentration, then experimentally altering encounter timing while maintaining chemical identity and average exposure should modify sensory coding or behavior in systems capable of temporal discrimination [16, 19, 20]. The expected outcome is not a universal response direction but a context-dependent change.

Second, if plume intermittency contributes to movement decisions, then matched chemical quantities arranged into different temporal patterns should alter trajectories in insects whose search depends on encounter transitions [13, 14]. The magnitude and direction of these effects should vary among taxa and movement modes.

Third, identical plume conditions should produce different actions after changes in memory or physiological state. Learning studies [24, 27], host-seeking regulation [29], and state-dependent sensory modulation [30] support this possibility, but they do not establish one shared mechanism.

Fourth, population and community patterns should not be assumed from individual mechanisms. Variation among mosquito populations [8] and floral visitor associations [10] suggests that ecological scaling is possible, but causal links require direct testing.

A complete validation program would combine realistic dynamic odor environments, neural or sensory measurements, movement tracking, state manipulation, and field comparison. Current evidence supports these components separately, not the complete predictive architecture.

Results and Discussion

Chemical ecology has often separated odor production, plume transport, sensory coding, learning, and movement into specialized research domains. This specialization has generated powerful knowledge but can obscure the transitions through which a physical chemical landscape becomes behaviorally meaningful.

The framework proposed here does not argue that insects possess a single chemical-habitat mechanism. Instead, it organizes existing evidence around a conditional transformation: external chemical structure provides opportunities, but behavioral relevance emerges only after organism-specific interpretation.

The strongest evidence concerns individual components. Dynamic stimuli alter sensory processing [5, 16–18], intermittent encounters influence movement [13–15], learning changes odor responses [24], physiological state modifies sensory valuation [29, 30], and multimodal cues influence action selection [34]. The unresolved question

is whether these components interact predictably enough across species and environments to produce a general explanatory architecture.

Several boundaries remain critical. Drosophila provides exceptional mechanistic resolution but cannot represent all insects. Mosquito studies provide strong examples of host-seeking regulation but are specialized systems. Pollination networks and population studies provide ecological relevance but generally cannot identify individual causal mechanisms.

Molecular findings require similar caution. Changes in chemosensory expression or neuromodulatory markers may accompany behavioral plasticity, but molecular association does not establish a causal behavioral switch [31, 32]. Likewise, evidence-accumulation mechanisms demonstrated in defined discrimination tasks should not automatically be extended to free-ranging navigation [33].

The proposed concept of functional behavioral habitat therefore remains a research hypothesis. Its value is organizational: it provides a way to connect chemical physics, sensory biology, memory, physiology, and movement while preserving the boundaries between them.

Conclusion

This cross-sectional study investigated sexual satisfaction in pregnant women with Candida vaginitis. The study showed that there is a relationship between sexual satisfaction and Candida infection. Study of Sexual Condoms in Brazilian Women, by Jensen *et al*., investigating the sexual function and quality of life of patients with and without treatment of vulvovaginal disorders, and study by Shah-hosseini *et al*. on factors affecting sexual satisfaction in women is consistent [9-18]. The results of this study indicate that genital system involvement with vaginitis can predict sexual dissatisfaction in women. According to the numerous studies, sexual satisfaction means a person's pleasant feeling of sex, integration, and harmony between one's mind, emotion, and body, and is part of a woman’s health and an essential component of life, influenced by many factors such as age, culture, religion, physical ailments, pregnancy, lifestyle, childhood events, previous generations experiences, history of sexual coercion, economic status, communication satisfaction, intimacy, sexual self-disclosure, non-sexual self-disclosure, and self-esteem [31]. the study of the effect of colporrhaphy surgery on women's sexual satisfaction, Allah Yar Mahmod Salehi, and Ghanbari *et al*. are in line with the comparison of sexual satisfaction in both total abdominal hysterectomy and sub-total abdominal hysterectomy [3, 4]. Sexual satisfaction is a general assessment of the marital status of individuals, and in the culture of developing countries, including Iran, most women place more importance on their husband's satisfaction than their own [32]. Pregnant mothers studied in this work had a negative evaluation of their marital relationship.

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