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Pathways of Non-Salient Factors Affecting Attention in Human-Computer Interaction

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Abstract. Subtle environmental stimuli, such as micro-animations, color hierarchy imbalances, and low-level background noise, can unconsciously shape user attention and cognitive load. Despite their ubiquity in digital interfaces, these non-salient factors remain underexplored in current Human-Computer Interaction research. This study employs literature review and case analysis to analyze neural correlates (e.g., frontal alpha oscillations), behavioral indicators (e.g., mouse trajectories, reaction times), and subjective self-reports (e.g., mind-wandering). The paper outlines multi-dimensional pathways through which attention is subtly eroded. This paper aims to introduce the dynamic interaction mechanism between environment, user, and task association, and explain the path by which non-salient factors influence user attention. The review further explores adaptable measures in interface design, providing strategies for both general users and vulnerable groups such as individuals with ADHD and the elderly. This study provides certain theoretical guidance and methodological reference for Human-Computer Interaction design.

Keywords: Attention drift, Non-salient Distractions, Cognitive load, HCI, Behavioral indicators

1. Introduction

In the modern digital context, attention, as a limited cognitive resource, faces severe challenges. Current human-computer interaction (HCI) research primarily focuses on the mechanisms of explicit distractions (such as system notifications), while researchers often neglect potential non-salient ones (e.g., subtle interface animations, imbalanced colour contrast, background sounds, and temperature changes). These seemingly minor environmental factors through preconscious pathways, thereby reducing task performance. It is evident that conventional attention research is encumbered by inherent limitations, amely the challenge of effectively capturing subtle fluctuations in attention through a single behavioural indicator. Recent studies have demonstrated that a multimodal approach integrating neurophysiological measurements (e.g., electroencephalographic signals), detailed behavioural analysis (e.g., mouse trajectories), and subjective reports can more comprehensively reveal the dynamic process of attention fluctuations.

This study uses literature review to systematically examines the mechanisms by which non-salient features influence sustained attention by integrating interdisciplinary findings from cognitive neuroscience, behavioural experimentation, and interface design. It constructs a theoretical

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framework of dynamic coupling between “environment-user-task”. The research provides important theoretical basis and practical guidance for developing adaptive interface systems with attention-aware capabilities, thereby ultimately enabling smarter and more inclusive digital interaction experiences.

2. Literature review

2.1. Theoretical foundations

2.1.1. The impact of non-salient factors on attention

Non-salient environmental factors refer to the subtle or less conspicuous elements from the environment that have the capacity to influence an individual’s ability to concentrate, even these elements may not be immediately apparent. In contrast, salient stimuli such as loud noises or bright lights, which are naturally attractive to observers, whereas non-salient factors operate in more subtle ways.

2.1.2. The theory of affordances

This theory describes “action possibilities” latent in the environment. These possibilities, which are objectively measurable and independent of the individual’s ability to recognize them, always exist in relation to agents and therefore depend on their capabilities. As Gibson emphasizes, perceivers do not passively receive stimuli but actively extract information from the ambient array that specifies affordances [1]. According to the theory, non-salient features exist in “covert forms”, such as low-saturation colours. When these factors are consistent with task demands, attention is enhanced; when they conflict with demands, attention is unconsciously consumed.

2.1.3. Embodied cognition

The idea of cognition is based on the continuous interaction between the human body and the environment [2]. Cognitive processes use tools and structures found in the environment. This idea matches the view of human cognitive development as 'a kaleidoscope of complex effects that fuel the flexible and open-ended character of thought and action’ [3]. It also explains why our brains are ready to seek close links with non-biological resources [4].

This perspective suggests that even non-salient features, for instance, low-level visual or auditory cues, can influence attentional engagement through embodied and unconscious mechanisms.

Critically, environmental influences can unconsciously change the brain’s structure and trigger unconscious changes to the nervous system in response to environmental demands [5]. This is clear in how “early learning causes lasting changes to the nervous system” and how “developmental changes reorganise cognition in significant ways”.

2.1.4. Load theory of attention

Research shows that high perceptual load reduces distractor interference, whereas working memory load or dual-task coordination load increases it [6]. This happens because high load on cognitive control functions (e.g., working memory) depletes the capacity for active control, resulting in increased processing of irrelevant distractors. Specifically, under high working memory load, distractor compatibility effects were significantly greater than under low load, demonstrating that

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cognitive control failure amplifies distraction. This suggests that non-salient environmental stimuli may interfere more easily with task performance when cognitive resources are already limited. As summarized by Lavie, perceptual load exhausts early sensory capacity, blocking distractor perception; cognitive load impairs late control, allowing perceived distractors to hijack behavior [7].

2.2. Key empirical studies and perspectives

Previous studies have examined how subtle environmental influences impact attention and performance. Kwallek, for example, found that colour pleasantness increases with saturation, which may affect attention allocation [8]. Researchers often use simplified stimuli like pictures or slides, which do not reflect real office conditions. In auditory research, Yadav showed that multi-talker "babble" often degrades task performance at low sound pressure levels, suggesting spatial release from masking (i.e., reduced distraction when sounds originate from different locations) [9].

Lighting systems with individual control, such as dimming, have been found to improve sustained attention and motivation, whereas fixed lighting tends to result in performance decline [10]. Similarly, thermal discomfort (e.g., at 30°C) has been shown to significantly reduce task speed, especially when performance feedback is provided [11]. While these studies provide strong evidence for the impact of environmental variables on cognitive performance, most investigate individual factors in isolation and rely primarily on task-based evaluations. There is limited integration of neural, behavioural, and subjective data, and little attention has been paid to how such subtle influences could inform adaptive interface design in HCI.

3. Pathways of non-salient factors influencing perception and subtle attention drift

3.1. Neurophysiological traces

Neural indicators reveal how non-salient environmental factors subtly disrupt attention. Electroencephalographic (EEG) alpha waves, for instance, reflect attentional shifts. It increased frontal low-alpha activity (linked to mental fatigue) and reduced parietal upper-alpha power (indicating inefficient stimulus processing) emerges as attention wanes, even due to subtle discomfort [12]. These changes suggest the brain shifts into an internally oriented state, impairing task focus.

Similarly, the P300 (an ERP component) acts as a sensitive marker. Non-salient disturbances reduce their amplitude, signaling silent erosion of attentional efficiency [13]. Its link to frontal-dopaminergic and parietal-norepinephrine systems confirms reliability in tracking distraction, especially during multitasking [13].

3.2. Behavioral performance

Behavioral performance reveals how non-salient environmental factors subtly shape attention, even when unperceived. Research using Continuous Performance Tasks (CPTs) has shown that reaction time (RT) patterns are linked to attentional states. It also found that faster RTs were associated to errors and mind-wandering in Situational Awareness Training (SART) tasks [14]. Real-time triggering methodologies have shown that fast RTs correlate with lapses, while slow RTs correlate with focused states, proving RTs' value as an objective attentional marker.

Mouse movements further reflect attention. Deviations in trajectory (e.g., during search tasks) predict distraction, and increased movement frequency is associated with higher cognitive load—this validates passive tracking as a reliable gauge of mental effort [15]. As changes in the body

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patterns indicate stress—pupils dilate, brain waves show concentration, and heart rate and sweating reveal physical reactions—individual differences may affect workload capacity. Evidence suggests that excessive cognitive load can impede performance and focus [16]. Reduced accuracy may not stem from overt distraction, but from subtle stressors that compromise sustained attention.

WebGazer provides a natural experience without explicit calibration by leveraging user interactions such as clicks and cursor movements [12]. It exploits saccades by buffering eye features within 500 milliseconds and uses gaze-correlated cursor movement to infer user attention [12]. Although smaller eye movements are not discussed, the study links mouse movement to gaze, showing that people's cursor patterns reveal what they focus on. WebGazer's model approximates gaze and falls back to fixations during inactivity, achieving a mean error of 4.17, showing its effectiveness [12]. Thus, gaze movement offers another key indicator of attentional change.

3.3. Subjective self-reports

The phenomenon of mind wandering, also known as task-unrelated thoughts (TUT), is most often assessed through reports that are given by the individual concerned. Individuals report that mind wandering occurs more frequently over time.. They also report, for instance, that it occurs more frequently in the second half of a lecture. The longer individuals engage in a task, the slower their responses and the less accurately they detect stimuli. This suggests a close association between changes in self-reported mind-wandering frequency and changes in task performance. The results indicate that people who have greater increases in TUT tend to exhibit poorer performance, further supporting this relationship. This means that changes over time in self-reported attention over time can be used to predict behavioral outcomes [17]. Increases in reported task-unrelated thoughts often arise without users being fully aware of the cause, reinforcing the notion that ambient non-salient features can unconsciously drain attention.

EEG signals, reaction times, mouse trajectories, and eye movements, as well as subjective self-reports feedback, collectively reflect changes in attention, even when users are unaware. These indicators constitute the pathways through which non-salient environmental factors influence perception and subtle attention drift. The integration of these indicators enables interactive systems to detect attention drift and provide targeted support in low-engagement scenarios.

4. Interface-level non-salient distractions and their impact on user attention

4.1. Subtle UI animation

Subtle UI animations, such as micro-motion effects, may also act as non-salient distractions that influence attention through neurophysiological pathways. As low-intensity visual stimuli, they can unconsciously redirect surplus attentional resources during high-load task processing, increasing cognitive load. This redirection is reflected in elevated low-alpha power in the frontal lobe, a neural signal of hidden attentional depletion. Over time, this may cause mental fatigue and reduce task focus.

4.2. Color hierarchy imbalance

Research demonstrates that visual cues such as colour and motion can strongly capture attention [18]. As the scholars pointed out that "Participants engaged with the highlighted region for longer than any other". This remains true even under high cognitive load, when tunnel vision may reduce peripheral awareness. However, when low-priority elements are visually enhanced, this imbalance in

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colour hierarchy can covertly divert attention. Although these low-intensity cues are not consciously noticed, they will redirect surplus cognitive resources. This increases cognitive load and elevates frontal low-alpha activity, which links to an indicator of mental fatigue and subtle attentional depletion. Over time, sustained focus weakens, even without users' awareness. Such effects also appear in slower reaction times or gaze shifts, linking to behavioural and neural markers of distraction.

4.3. Peripheral information overload

Non-central interface elements such as banner ads, sidebars, floating buttons, or recommended content often appear at the screen peripheries. These are not the main focus of a task, but they still move, blink, or stand out in subtle ways. Research shows that even when users ignore these elements during focused tasks, placing such elements within the main content still draws attention during casual browsing. This means that users may unintentionally expend cognitive resources processing irrelevant information. As a result, attention shifts, task accuracy drops, and users may feel tired or distracted unconsciously. These subtle environmental stimuli can increase cognitive load and lead to elevated frontal low-alpha EEG activity, reflecting the implicit consumption of attentional resources and the onset of mental fatigue. From an HCI perspective, systems should detect when users are deeply focused and hide or dim these elements to reduce unnecessary distractions.

5. Future design directions for attention-aware HCI systems

The design challenges center on three points. First, it is difficult for users and the testing processes to detect non-salient distractions. Second, there is a design trade-off between visual appeal and cognitive load. Meanwhile, differences in individual attention thresholds increase the difficulty of universal design.

5.1. Adaptive design for general users

To address those challenges, adaptive HCI should use adaptive user interfaces that construct user models "based on partial experience with that user", such as learning preferences from behavioral traces like document selections or form interactions [19]. For instance, systems such as Syskill & Webert optimize interactions—such as predicting desirable content—to refine interactions. While personalisation is often the main focus, these approaches show how behavioural data can adapt interfaces to user needs, indirectly supporting more efficient engagement. Future interface designs can use real-time behavioural signals to infer the users' attention. Interfaces can automatically adjust to reduce visual complexity, disable animations, and hide content during tasks requiring concentration. This helps maintain focus without manual adjustments, achieving a low-distraction environment.

5.2. Inclusive strategies for special user groups

For people with ADHD, concentrating or controlling their movements is often difficult, leading to a negative impact on concentration, behavioural inhibition, memory, and functional outcomes in their everyday lives [20]. Similarly, older adults find it difficult to ignore irrelevant information, making them more likely to be distracted and accidents. Therefore, in order to better support users with ADHD or the elderly, interface designs should reduce subtle distractions by limiting dynamic

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effects, simplifying layouts, and emphasising clear visual hierarchies. For ADHD users, linear task flows and minimal competing stimuli might help maintain focus. For older adults, improved readability and clutter-free designs will likely enhance task control. Based on these mentioned assumptions for inspiration, future research can explore adaptive systems that detect user sensitivity levels and adjust visual complexity in real time. These personalized design strategies may improve accessibility and sustained attention in diverse user groups.

6. Conclusion

This study highlights how non-salient environmental and interface-level factors may subtly shape user' attention. While users often remain unaware of these subtle cues, the combined evidence from neurophysiological, behavioral, and subjective pathways reveals that such factors can silently erode attentional resources and affect task performance.

The findings offer guidance for HCI practice. Adaptive systems could use real-time behavioural and neurophysiological signals to reduce implicit cognitive load, while inclusive strategies may address individual differences in attention, such as those in older adults and users with ADHD.

This study also has certain limitations. For example, it focused on the influence of visual non-salient factors in short-term tasks. Besides, this study mainly focuses on individual factors, without exploring the interaction between non-salient factors. Therefore, future work could examine how multiple subtle cues jointly influence attention to inform more comprehensive adaptive designs and verify performances in long-term tasks and across different age groups.

In conclusion, subtle environmental and interface design-related influences warrant more attention in interface research. The integration of multi-source attentional indicators can guide the development of systems that not only respond to users' needs but also protect their cognitive capacity in complex digital environments.

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