# The Integrated Warning Experience(IWE): A Theoretical Framework for Visual Warning Design Based on Biological Warning Signs

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Contemporary visual warning systems primarily rely on conspicuity—using strong contrasts in color, brightness, and spatial arrangement—to attract attention. However, these systems often fail to ensure accurate interpretation and appropriate user response, particularly among cognitively vulnerable populations and within complex environments. To complement this limitation, this study introduces the concept of distinctiveness as a perceptual factor that enhances discrimination and interpretation in visual warning perception. When auditory access is limited—as in hearing-impaired users or high-noise industrial contexts—visual warnings that depend solely on conspicuity often lead to interpretive failure due to the lack of perceptual differentiation. The study proposes the Integrated Warning Experience (IWE) as a novel theoretical framework encompassing the full user perceptual sequence—recognition, interpretation, and behavioral response—through directionally and distance-dependent design strategies. The framework is constructed by analyzing international visual warning standards, user information processing models (e.g., C-HIP), and real-world accident cases involving cognitively vulnerable and hearing-impaired users. Additionally, biological warning strategies—including aposematism, deimatic behavior, mimicry, and camouflage reversal—are examined to derive design principles integrating conspicuity and distinctiveness. Based on this multi-source analysis, the study proposes a user-centered visual warning model that adapts visual elements by distance range and incorporates visual feedback for cognitive closure. The proposed model represents the first phase in developing the IWE framework, limited to the visual modality. While empirical validation lies beyond the present scope, the theoretical structure provides a foundation for future quantitative modeling, experimental verification, and multimodal expansion. Ultimately, this research contributes to design theory by reframing visual warning as a design problem of perception, expanding the conventional focus on conspicuity toward a distinctiveness-based, inclusive design approach applicable to Human–Robot Interaction (HRI) and safety-critical environments.

***Keywords: Integrated Warning Experience (IWE), Bio-inspired Design, Visual Warning Systems, User-Centered Design, Human-robot Interaction (HRI)***

# 1 Introduction

## 1.1 Research Background

In nature, diverse sensory-based warning strategies have evolved to promote survival. For instance, the high-contrast blue rings of the blue-ringed octopus (Hapalochlaena spp.), the sudden volumetric inflation of pufferfish (Tetraodontidae), and the vivid body coloration of poison dart frogs (Dendrobatidae) serve as visual deterrents against predators. These strategies—employing high-chroma/luminance contrasts, abrupt morphological changes, and repetitive patterns—trigger instinctive aversive responses regardless of prior learning.

In contrast, warning systems in human environments rely largely on symbols and text, using high-contrast colors and geometric shapes to enhance visual salience (Wogalter et al., 2006). However, such systems assume a basic level of literacy and interpretive ability, often leading to perceptual or behavioral discrepancies. While graphic elements provide context and draw attention, semantic meaning is largely conveyed through text (Oh, 2008). Consequently, text-based warnings impose cognitive load on low-literacy users and pose accessibility challenges for the elderly, illiterate individuals, non-native speakers, and those with hearing impairments (Son & Yi, 2018).

Moreover, in interaction-rich settings like Human-Robot Interaction (HRI), or in industrial environments with high noise levels or complex visual backgrounds, auditory warnings may be ineffective, and visual warnings may go unnoticed or misinterpreted. Although multimodal approaches are ideal, about 70–80% of external stimuli are processed visually (Mandal, 2003). Given this dominance and the practical constraints of real-world interfaces, visually mediated warnings remain a critical element in user-centered warning design. Accordingly, this study highlights the need to refine visual warning strategies as a foundational step toward multisensory interface strategies.

## 1.2 Research Objective

This study defines the Integrated Warning Experience (IWE) as a new theoretical framework encompassing recognition, interpretation, and response in user perception. IWE is introduced to address the structural limitations of conventional visual warning systems, which often rely on fragmented, strong contrasts in color, brightness, and spatial arrangement. Through analysis of international standards, cognitive processing models, and accident cases involving cognitively vulnerable users, the study identifies key limitations. It then derives visual design principles from biological warning strategies and extracts application-ready elements from nature-based cases. These findings support the formulation of a user-centered visual warning model, serving as the first phase of the IWE framework. The research objectives are summarized in the following table.

*Table 1. Summary of Research Objective*

| Objective |
| --- |
| 1. Identify limitations in existing visual warning models. |
| 2. Define the Integrated Warning Experience (IWE) covering perception, interpretation, and response. |
| 3. Propose IWE as a user-centered visual warning model informed by biological signaling. |
| 4. Extract visual design principles from biological warning strategies. |
| 5. Establish IWE (visual modality) as the first phase of model development. |

# 2 Theoretical Background

## 2.1 Warning Model

### 2.1.1 International Standards

International standards for visual warning design are primarily structured around two elements: color and shape. These components form the fundamental basis for enhancing perceptual detection and cognitive interpretation of warnings. Although shape specifications differ across standards, most employ consistent geometric forms, including triangles, circles, and squares, to ensure visual clarity and semantic consistency. The key guidelines are presented in the following table

.

*Table 2. International Standards in Visual Warning Model*

| Standard | Core Components | Color and Meaning | Characteristics | Organization / Country (Year) |
|---|---|---|---|---|
| **ISO 3864** | Safety colors, shapes, symbols | Red (Prohibition), Yellow (Warning), Blue (Mandatory), Green (Safe) | Global standard; clear color–meaning correspondence | ISO / International (1984) |
| **ANSI Z535** | Signal words, safety colors, symbols | Red (Prohibition), Yellow (Warning), Blue (Mandatory), Green (Safe) | Text-focused; legal compliance; industrial use | ANSI / USA (1991) |
| **KS A ISO 3864** | Color, shape, pictogram | Red (Prohibition), Yellow (Warning), Blue (Mandatory), Green (Safe) | Korean national standard based on ISO 3864 | KATS / Korea (2007) |
| **JIS Z9103** | Safety colors, shapes, text | Red (Danger), Yellow (Caution), Blue (Instruction), Green (Safety) | Factory-focused; ISO-compatible | JISC / Japan (1993) |

### 2.1.2 Communication–Human Information Processing (C-HIP) Model

Warnings serve as a key medium for communicating residual risks to users, with color being especially effective in drawing visual attention and conveying danger intuitively. The Communication–Human Information Processing (C-HIP) model conceptualizes warning communication as an interaction among physical design elements (e.g., color, shape, spatial layout), semantic content (e.g., wording), and user-related factors such as experience and cognitive ability (Wogalter, 2012). This framework, illustrated below, is hereafter referred to as the C-HIP model.

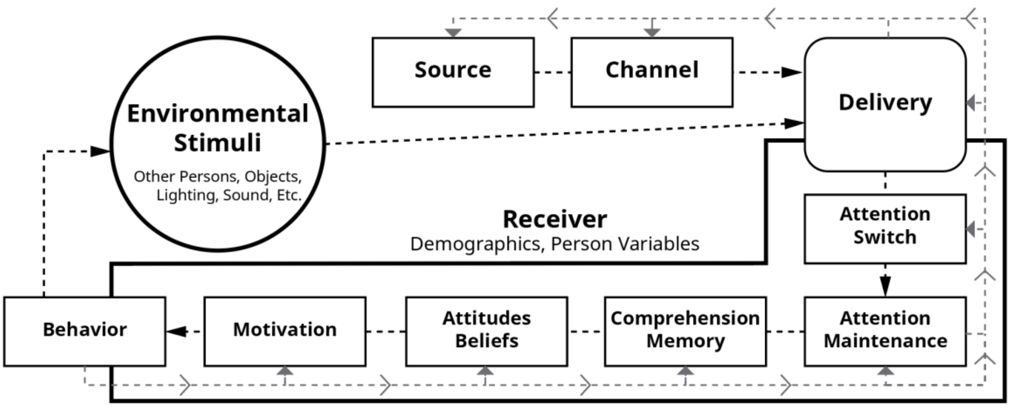



*Figure 1. C-HIP Model*

## 2.2 Biological Model

This model, referred to as the 'Predation Sequence', is grounded in predator–prey interactions and explains how biological warning expressions lead to avoidance behaviors. Stages 1–4 are classified as Primary Defenses—preemptive strategies such as camouflage, aposematism, and threat displays activated before detection (Endler, 1991). In contrast, stages 5–6 are Secondary Defenses, involving reactive behaviors after predator engagement (Caro, 2005). Each stage reflects a structured shift in threat perception and survival response.

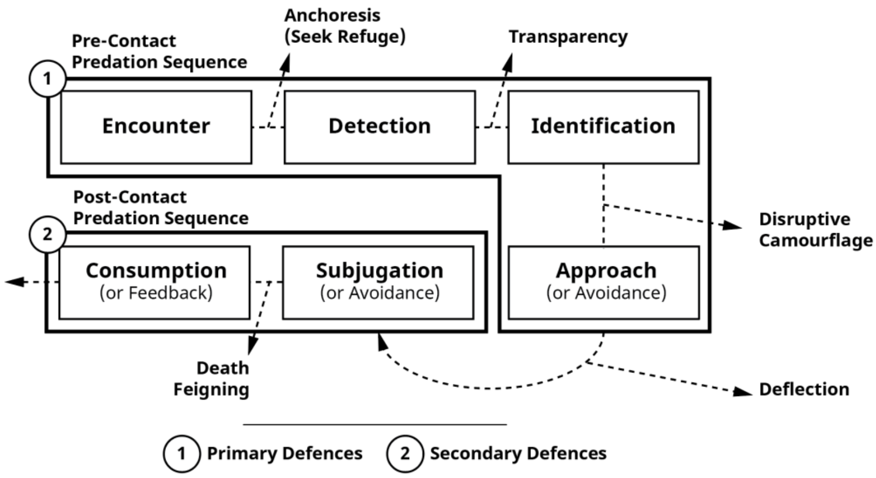



*Figure 2. Predation Sequence Model*

## 2.3 Limitations

Current visual warning standards emphasize conspicuity by employing high-chroma colors and strong luminance contrasts to attract attention (Hailman, 1977; Stevens & Cuthill, 2006). 'Conspicuity' refers to how readily a visual signal—via color, brightness, or motion—can be detected (Hailman, 1977; Stevens & Cuthill, 2006). However, excessive reliance on such cues can cause overstimulation, fatigue (Wogalter, 2006), and confusion due to competing signals (Edworthy & Hellier, 2006). In visually cluttered settings, semantic discrimination becomes harder (Merilaita & Ruxton, 2007). Here, 'Distinctiveness' becomes vital. Defined as the visual separability of colors, patterns, or shapes from the background, distinctiveness supports interpretation and learned recognition (Sherratt & Beatty, 2003; Hailman, 1977). Thus, effective warning design requires both conspicuity and perceptual distinctiveness. The C-HIP model's limitations in this regard are summarized below.

*Table 3. Limitations of Current Visual Warning Models*

| Limitations | Researcher (Year) |
|---|---|
| Attenuation of warning effectiveness due to contextual factors such as ambient light, noise, or competing stimuli. | Wogalter (2012) |
| Lack of tailored strategies for older adults and individuals with low literacy. | |
| Absence of effective feedback systems to guide user response after message reception. | |
| Insufficient differentiation in warning modality based on proximity (e.g., distant vs. close range). | |
| Emphasis on post-recognition response rather than early detection and avoidance facilitation. | |

# 3 Analysis

## 3.1 Methodology

This study proposes a theoretical framework for the Integrated Warning Experience (IWE), focusing on visual modality as its first phase. The methodology involves three key steps: (1) analyzing international visual warning standards and user information processing models (e.g., C-HIP) to identify structural limitations, (2) extracting visual design principles from biological threat signaling strategies, and (3) reviewing real-world accident cases involving cognitively vulnerable users. Through this triangulated approach, the study identifies perceptually effective visual elements and reorganizes them into a stage-based model that integrates both conspicuity and distinctiveness. This process provides a theoretical basis for structuring user-centered warning perception and response.

The detailed phases of this process are summarized in the following table.

*Table 4. Research Methodology*

| Step | Summary of Methodology |
|---|---|
| 1 | To identify structural limitations in existing visual warning models. |
| 2 | To extract design principles from biological threat-signaling strategies. |
| 3 | To derive visual warning components through analysis of biologically grounded cases. |
| 4 | To examine vulnerabilities in current warning systems through real-world incident analysis. |
| 5 | To define the Integrated Warning Experience (IWE)<br>as a model encompassing perception, interpretation, and response. |
| 6 | To theoretically propose IWE as a structured,<br>User-centered visual warning framework. |

## 3.2 Biological Cases

### 3.2.1 Warning Displays in Biological Systems

To ensure survival against predation, many species have developed diverse warning display strategies designed to trigger predators' instinctive avoidance responses through sensory stimulation (Stevens & Ruxton, 2012). These include Aposematism (high-contrast warning coloration), Postural Display (morphological expansion such as body inflation), Deimatic Behavior (startling movements or the sudden exposure of threatening forms), and Flash Coloration (brief display of vivid patterns used as a secondary cue). Importantly, such strategies do not rely solely on increasing signal intensity or conspicuity, but evolve to enhance distinctiveness by aligning with the perceptual tendencies of predators (Ruxton et al., 2018; Stevens, 2007).

Therefore, these biological cases offer valuable insights not only for conspicuity-driven designs but also for enhancing the distinctiveness of warning signals. Additionally, in this continuum of perceptual strategies, this study also includes camouflage—not as a directly applicable form of warning expression, but as a perceptual counter-model that defines the boundary where visibility collapses. By examining camouflage as the inverse condition of perception, the research identifies how the mechanisms of non-detection can be conceptually reversed to strengthen conspicuity and distinctiveness in design. This approach allows biological warning systems to be interpreted not merely as mechanisms of visibility, but as an integrated field encompassing both visibility and its absence. In accordance with this approach, the present study organizes visual warning mechanisms derived from biological models into a hierarchical framework of primary and secondary strategies. The selected examples and classifications are summarized in the following tables.

*Table 5. Primary Categories of Biological Warning Display Concepts*

| Category | Definition | Key Insight | Researchers(Year) |
|---|---|---|---|
| **Aposematism** | Persistent visual signalling of toxicity or unpalatability. | Deterrence through stable, conspicuous color patterns. | Edmunds (1974); Halpin et al. (2008a) |
| **Postural Display** | Signal amplification through body enlargement or pose changes. | Enhancing visibility or perceived threat via bodily exaggeration. | Ruxton et al. (2008) |
| **Deimatic Behavior** | Sudden, temporary displays to startle predators. | Eliciting aversive responses via unexpected visual exposure. | Stevens (2007); Maldonado (1970) |
| **Reflexive Polymorphism** | Context-sensitive variation in visual signals. | Adaptation of warning display depending on external stimuli or perception. | Owen & Whiteley (1989) |
| **Signal Interpretability** | Design of signals for accurate decoding by receivers. | Alignment of signal clarity with cognitive and perceptual capacities of observer. | Stevens (2007); Guilford (1990) |
| **Frequency-Dependent Selection** | Trait survival linked to predator response frequency | Trait prevalence shaped by predator familiarity and learning. | Fisher (1930); Allen (1989a) |
| **Distance-Dependent Patterning** | Shifting display strategy based on observer distance. | Concealment at a distance, conspicuous signaling at proximity. | Tullberg et al. (2005); Barnett et al. (2017) |

*Table 6. Secondary Categories of Biological Warning Display Concepts*

| Sub-Category | Definition | Key Insight | Researchers(Year) |
|---|---|---|---|
| **Positive FDS** | Frequent traits reinforce predator learning. | Common patterns become advantageous through repeated avoidance. | Levin (1988) |
| **Negative FDS** | Rare traits avoid learned targeting. | Unfamiliar morphs have survival advantage due to lack of recognition. | Partridge et al. (1988); O'Donald & Majerus (1988) |
| **Apostatic Selection** | Selective advantage for rare phenotypes. | Subtype of negative FDS promoting trait diversity. | Clarke (1962); Greenwood (1985) |
| **Conspicuity vs. Camouflage** | Contextual balance between visibility and concealment. | Adjusting visibility according to environmental or distance-based context. | Stevens (2007); Tullberg et al. (2005) |
| **Edge Detection Disruption** | Breaking object boundary recognition. | Reducing object identification through high-pattern interference. | Stevens & Cuthill (2006); Merilaita et al. (2017) |
| **Flicker-Fusion Camouflage** | Motion-induced blending of pattern into background. | Fast movement reduces detectability via perceptual blurring. | Stevens (2007); Ruxton et al. (2008) |

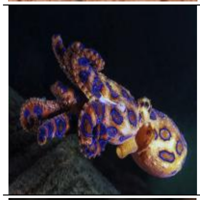
The above tables illustrate that biological warning expressions function as composite strategies incorporating background conditions and viewing distance, effectively triggering predators' perception–avoidance responses. These mechanisms highlight potential design elements for intuitive visual warnings, particularly in environments involving cognitively vulnerable populations.

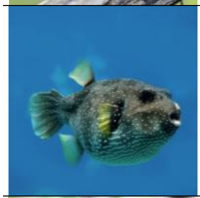
Grounded in the preceding theoretical framework, this study extracts key visual components from such biological strategies and reorganizes them into structured design parameters applicable to user-centered warning interface development.

### 3.2.2 Applied Cases of Warning Expression

Based on the previously analyzed biological warning strategies and perceptual mechanisms, this study selects representative species exhibiting visually grounded signals, particularly within the Primary Defences stage of the predation sequence model. To structure the evaluation, five criteria were derived from existing literature to assess both *conspicuity* and *distinctiveness* in visual signaling: (1) high-chroma and contrasting colors, (2) repetitive or regularized patterns, (3) threat-induced transformation of color or form, (4) interspecies mimicry in color or shape, and (5) modulation of *warning signals* in response to viewing distance and background. These criteria inform the selection and classification of biological cases, summarized in the following table.

*Table 7. Applications of Warning Expression Design*

| Image | Species | Display Strategy | Visual Elements | Strategic Characteristics | Researchers (Year) |
|---|---|---|---|---|---|
|  | Coral snake (Micrurus frontalis) | Aposematism | Repeating bands of red, yellow, and black | High toxicity paired with conspicuous color pattern to facilitate predator learning | Smith (1975) |
|  | Blue-ringed octopus | Aposematism (Contextual) | Bright blue rings activated under threat | Situational high-contrast signal display | Caro (2005) |
|  | Sea slug (Chromodoris spp.) | Aposematism | Fluorescent blue and other vivid colors | Signals sequestered sponge toxins through conspicuous coloration | Gosliner et al. (2008) |
|  | Lady beetle (Coccinellidae) | Aposematism | Red background with black spots | Visual display indicating chemical defense (toxicity) | Arenas & Stevens (2015) |
|  | Poison dart frog (Dendrobatidae) | Aposematism | High-saturation body coloration (yellow, blue, orange) | Visual signal emphasizing toxicity | Ruxton et al. (2018) |

| | | | | | |
|---|---|---|---|---|---|
|  | Hornet (Vespidae) | Aposematism | Yellow and black banding | Conspicuous pattern signaling venomous sting | Ruxton et al. (2018) |
|  | Frilled lizard (Chlamydosaurus kingii) | Postural + Deimatic Behavior + Color Extension | Expanded frill and upright posture | Sudden display provides intimidation during surprise threat encounters | Shine (2008) |
|  | Pufferfish (Tetraodontidae) | Deimatic Behavior + Color Change | Inflated body posture + brightened body color | Visual and morphological intimidation display | Stevens & Ruxton (2012) |
|  | Swallowtail caterpillar (Papilio machaon) | Postural + Deimatic Behavior + Color Extension | Eversion of horn-like osmeterium organ | Sudden morphological change induces startle response | Olofsson et al. (2012) |
|  | Parasemia plantaginis | Aposematism + Disruptive Camouflage | High-chroma coloration with peripheral disruptive patterns | Combined display hinders both detection and identification | Honma et al. (2015) |
|  | Sepia officinalis (common cuttlefish) | Aposematism (Contextual - Dynamic Chromatic Adaptation)+Camouflage | Background-matching camouflage patterns | Real-time camouflage achieved within 0.5 seconds | Chiao et al. (2015) |

### 3.2.3 Camouflage Strategies

Camouflage is a biological strategy for avoiding visual detection by blending with the environment, which fundamentally contrasts with the intent of visual warning systems that aim to attract attention and signal danger. Since camouflage reduces conspicuity and distinctiveness, it is not directly applicable to design warning model (Shapley & Lennie, 1985; Graham, 1989; Bruce et al., 2003). Nevertheless, examining how camouflage disrupts visibility provides critical insight into the perceptual conditions that hinder detection—conditions that, when reversed, can inform strategies for strengthening visual conspicuity and distinctiveness.

For example, Merilaita et al. (1999) showed that similarity between prey and background enhances survival, implying that warning design should intentionally avoid such blending. Similarly, studies by Penacchio et al. (2015) and Cuthill et al. (2016) demonstrated that self-cast shadows under changing lighting conditions obscure detection, a principle that may inform brightness contrast strategies in User-centered warning model. Hailman (1977) further noted that reversing camouflage logic can increase conspicuity.

Among these, the principle of countershading—a shadow-based camouflage technique—offers key insight into how contrast modulation affects visual detection under variable lighting conditions. As demonstrated by Penacchio et al. (2015b), condition (a) yields the highest detectability, while condition (c) is most effective in achieving camouflage. These findings provide a theoretical foundation for applying shadow contrast manipulation within a user-centered warning model to enhance the clarity of visual signals.

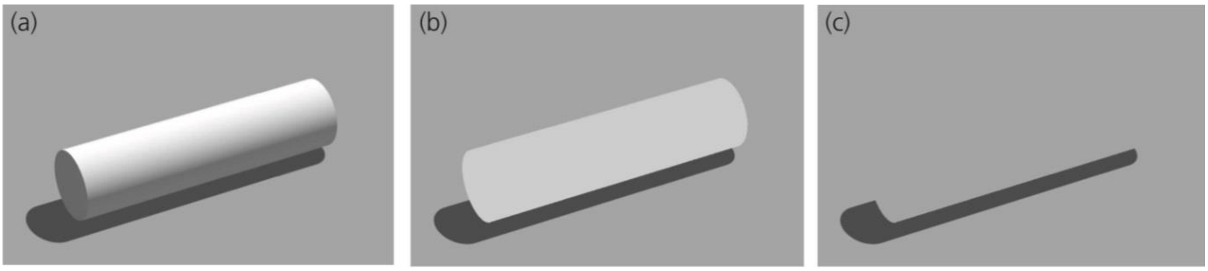



*Figure 3. Example of Self-cast Shadows*

The additional studies on camouflage expressions are summarized in the following table.

*Table 8. Camouflage-Related Studies*

| Category | Definition | Key Insight | Researchers (Year) |
|---|---|---|---|
| **Differential Blending** | Partial mismatch between object and background | Partial dissonance impairs detection due to incomplete blending | Cott (1940) |
| **Surface Disruption** | Irregular, repetitive surface patterns | Obscures object-background boundaries, hindering shape recognition | Stevens et al. (2009); Seymoure & Aiello (2015) |
| **Coincident Disruptive Coloration** | Pattern alignment with background | Pattern direction aligns with background, merging object outlines | Cuthill & Székely (2009) |
| **Maximum Disruptive Contrast** | High contrast at object edges adjacent to background | Sharp brightness/saturation difference impairs visual recognition | Stevens & Cuthill (2006); Stobbe & Schaefer (2008) |
| **Disruptive Marginal Patterns** | Bold edge motifs to fragment contours | Edge-focused patterns distort shape perception | Stevens et al. (2006); Todd et al. (2015) |
| **Camouflage by Disruption** | High contrast and segmentation | Breaks structural edges, confusing initial detection | Merilaita et al. (2017); Osorio & Cuthill (2013) |

Although camouflage strategies also involve elements of Conspicuity and Distinctiveness, they are fundamentally defined by minimizing both. In contrast, visual warning designs must enhance these attributes. Therefore, the principle of '*Disruptive Marginal Patterns*' should be applied in reverse: instead of fragmenting object boundaries, warnings should preserve clear and continuous outlines to improve signal salience.

### 3.2.4 Mimicry Strategies

Mimicry strategies such as Müllerian and Batesian mimicry demonstrate how warning coloration facilitates predator avoidance during the identification phase. Both utilize high chromatic contrast and distinctive patterning to signal toxicity, fostering learned recognition and deterrence (Ruxton et al., 2018; Smith, 1975; Gosliner et al., 2008). Although mimicry is not directly transferable to human-centered design, it provides an important reference for understanding how shared visual recognition across species groups enables rapid and consistent behavioral responses. This implies that uniform visual cues—when learned and reinforced within a population—can effectively facilitate immediate and intuitive interpretation, a mechanism conceptually aligned with the function of visual warnings.

Representative cases of Müllerian mimicry are summarized below.



*Figure 4. Müllerian mimicry - ex)Dendrobatidae*

Müllerian mimicry, observed in toxic species such as poison dart frogs, involves the convergence of color and pattern features to produce a consistent visual warning signal. This uniformity promotes predator learning through repeated exposure, enhancing avoidance behavior and survival rates among mimicking species (Stuckert et al., 2013; Symula et al., 2001). Such dynamics exemplify Positive Frequency-Dependent Selection (Positive FDS).

Representative cases of Batesian mimicry are as follows.


*Figure 5. Batesian mimicry) - ex)Chrysotoxum bicinctum*

As illustrated in the case of the hoverfly (left), Batesian mimicry involves non-toxic species imitating the visual characteristics of toxic models—such as bees (right)—to induce assumed threat recognition in potential predators. This strategy leverages visual resemblance to elicit avoidance behavior, despite the absence of actual toxicity (Howarth & Edmunds, 2000).

### 3.3 User Accident Cases

To demonstrate the perceptual limitations of existing warning systems, real-world accident cases were examined. These incidents revealed that many failures stemmed not only from the use of single-sensory alerts but also from insufficient distinctiveness across sensory modalities, leading to delayed or failed recognition. The analysis particularly focused on individuals with hearing impairments and cognitively vulnerable populations. Prior research indicates that hearing loss is often accompanied by increased cognitive vulnerability (Lee & Kim, 2011; Kim, 2003), and that users with low literacy levels are prone to misinterpreting graphic-based warnings, resulting in reduced comprehension and delayed response (Son & Yi, 2018).

Furthermore, industrial environments characterized by persistent auditory masking—due to the use of hearing protection devices (e.g., earplugs) or constant background noise—exhibit similar perceptual limitations, even among individuals without hearing impairments. In such conditions, users inevitably rely on visual cues as the primary perceptual channel. However, these visual warnings often emphasize conspicuity—brightness or size—without sufficient distinctiveness, making it difficult to differentiate the level or type of danger. This limitation is evident in both hearing-impaired users and industrial workers exposed to high noise levels, where visual dependency exposes the lack of perceptual differentiation in current warning systems. These scenarios underscore the critical need to consider similar perceptual constraints across user groups when evaluating warning system effectiveness. The selected cases encompass industrial safety accidents, failures in disaster response communication, and overlooked public alerts. Across these instances, recurring structural limitations were observed, including auditory dependency, absence of visually substitutive cues, and delayed user recognition. These empirical findings reveal the interpretive failure caused by current visual warning systems and reinforce the necessity of enhancing user-centered, visually grounded warning expressions.

A structured summary is presented in the following table.

*Table 9. User Accident Cases*

| Case | Key Insight | Source (Year) |
|---|---|---|
| **Auditory-inaccessible : fire incident** | No visual cues → delayed evacuation & blocked rescue | Bae, D. W. (2021) |
| **Limited auditory–visual cues: evacuation delays** | Inadequate multimodal alerts → increased disaster risk for users with auditory limitations | Wood & Weisman (2003) |
| **Auditory-centered failure : subway accident** | Janitor unaware of oncoming train → lack of visual warning led to fatality | Dong-A Science (2017) |
| **Verbal-only cues : police incident** | Missed spoken commands → misinterpreted intent led to fatal outcome | TIME (2016) |
| **Low literacy in sign-reliant communities** | Limited written language access → text-based warnings not fully effective | Lee & Kim (2011); Kim (2003) |
| **Cochlear device users : perceptual gaps** | Hearing aids insufficient → auditory-only warnings often undetected | Ko & Kim (2021) |
| **Pictogram ambiguity : low literacy** | Higher misinterpretation rates among users with limited reading proficiency | Beusekom et al. (2016) |

The summarized cases demonstrate that individuals—particularly those with hearing impairments—face direct risk due to the structural limitations of auditory-centered warning systems. Emergencies can be classified into industrial, domestic, and disaster-related contexts, all of which predominantly depend on auditory cues such as alarms, sirens, or public broadcasts. This reliance places non-auditory users at a systemic disadvantage, delaying recognition and impairing timely response.

### 3.4 Sequence Structuring

To propose improvements to the C-HIP model, this study seeks to simplify the sequence structure by drawing on structural similarities between the Predation Sequence and the C-HIP model. Two hypotheses guide this restructuring: First, stages with similar functional roles can be integrated. Second, prioritizing the early phases of the Predation Sequence—specifically, the Primary Defences (Stages 1–4)—is deemed appropriate, as these stages emphasize rapid threat avoidance before full exposure to danger. The restructured sequence is summarized in the following table.

*Table 10. Behavioral Sequence Structuring*

| Predation Sequence | C-HIP Model | Integration |
|---|---|---|
| **Encounter** | **Source + Channel** | Initial physical contact point where the warning signal is transmitted via the chosen sensory channel. |
| **Detection** | **Attention Switch + Attention Maintenance** | Onset of attentional engagement, where attention is drawn and maintained toward the stimulus. |
| **Identification** | **Comprehension + Memory** | Signal meaning is interpreted through comprehension and memory recall, enabling recognition. |
| **Approach / Avoidance** | **Attitude / Belief + Motivation** | User forms an attitude or motivation toward the warning, deciding between engagement or avoidance. |
| **Subjugation / Avoidance** | **Behavior** | Behavioral execution occurs—either an avoidance action or continued interaction. |
| **Consumption / Feedback** | **Environmental Stimuli + Message Delivery** | Outcome feedback or stimulus exposure informs future responses or modifies signal delivery. |

## 4 Results

### 4.1 Definition of Design Elements

The Communication–Human Information Processing (C-HIP) model offers limited capacity to account for the effects of environmental background variability on warning effectiveness and does not explicitly incorporate behavioral feedback. To address these limitations, this study conducts case-based analyses to extract critical design elements by considering both visibility and discriminability in relation to key design parameters.

The identified components include color contrast, brightness contrast, pattern, shape, edge, and proxemics. Additionally, self-cast shadow is included as a context-dependent variable reflecting interaction with background conditions.

While the C-HIP model primarily emphasizes visual salience through chromatic and luminance contrast, the present study extends its framework by incorporating discriminability-enhancing elements to improve perceptual clarity. The following table summarizes these components.

*Table 11. Design Elements for Warning Expression*

| Category | Design Element | Research Content | Element Review |
|---|---|---|---|
| **Conspicuity** | Color Contrast | Contrast in brightness and saturation affects the predator's visual detection. | Use strongly contrasting colors with the background to induce rapid warning detection. |
| | Brightness Contrast | Brightness contrast directly influences detection efficiency and determines the priority of visual stimuli. | Use tones that are either brighter or darker than the ambient illumination. |
| | Edge | Edges play a key role in early visual recognition during detection. | Emphasize and place clearly defined edges around object contours. |
| | Color Diversity | Various warning colors are easily recognized by predators. | Use diverse combinations of warning colors (Note: recognition rates decrease when conveying more than three meanings or using more than four color combinations. Chapanis, 1994; Mayhorn et al., 2004c). |
| | Spatial Positioning | Recognition of positional information affects detection speed and interpretive accuracy. | Place in the central visual field or upper line of sight of the user. |
| | Motion Amplification | Sudden motion acts as an attention stimulus. | Enhance visual motion through blinking, animation, etc., when a warning is triggered. |
| **Distinctiveness** | Shape Distinctiveness | Symbolic or intuitive shapes facilitate meaning recognition. | Use simplified, symbolic shapes to convey warning meanings. |
| | Repetitive Patterning | Repetitive patterns promote object identification and predator learning. | Provide visual regularity using consistent stripes, dots, etc. |
| | Functional Color Differentiation | Visual systematization between warning and non-warning information is necessary. | Maintain consistent warning color coding (e.g., red = immediate response). |
| | Visual State Separation | The change in state before and after a warning must be clearly distinguishable. | Use color/pattern changes to indicate state transitions (e.g., blue → red). |
| **Mixed** | Proxemics | Detection occurs at a distance, identification occurs at close range. | Emphasize high-brightness, high-saturation colors at a distance; use shape and pattern-centered elements at close range. |
| | Self-cast Shadows | Recognition rates vary depending on the separation between object and background under weather conditions. | Compose brightness contrast in warning expressions by considering intended background and weather conditions. |
| | Aposematic Signal Resemblance | Higher similarity in color and pattern to the background enhances prey survivability through visual blending. | Design the color and pattern of warning expressions to be clearly distinct from the intended environmental background. |
| | Redundancy | Color-text combinations and hierarchical color structuring reduce misunderstanding in risk perception and enhance clarity in information delivery. | Use color-text pairings to deliver clear intent, and apply hierarchical warning color systems (e.g., red–orange–yellow) (Wogalter et al., 2012; ANSI Z535). |

### 4.1.1 Design Elements by Distance Range

Although biological warning displays vary depending on predator proximity, distinguishing between pre- and post-encounter threat responses (Caro, 2005), the C-HIP model does not reflect distance-dependent variation in warning design. To address this gap, the present study proposes a visual response structure that adapts design elements based on spatial distance.

Tullberg et al. (2005) demonstrated through an experiment using *Papilio machaon* caterpillars that identical colors and patterns yield different perceptual effects depending on viewing distance. At a distance, the caterpillar's coloration blends into the background (crypsis), while at close range, it functions as aposematic signaling through high chromatic contrast and repetitive patterns. This indicates that single visual elements can serve dual roles, depending on user distance, and that warning designs should similarly adapt across spatial ranges.

Additionally, Merilaita et al. (2017) emphasized that inadequate distinction from the background may hinder detection, highlighting the need to consider brightness and saturation contrast in relation to distance.

Based on these findings and the identified limitations of existing models, the following table outlines a distance-based strategy incorporating both conspicuity and distinctiveness.

*Table 12. Design Elements by Distance Range*

| Distance Range | Design Objective | Design Elements |
|---|---|---|
| **Long Distance**<br>(Encounter – Detection) | **Enhance *Conspicuity*** – Facilitate rapid detection and visual attention | High chroma/brightness contrast, simple edges, central or upper placement, minimal info |
| **Close Distance**<br>(Identification – Approach) | **Enhance *Distinctiveness* –** Support accurate interpretation of warning content | Repetitive patterns, symbolic shapes, color transitions, increased info density |

## 4.2 Integrated Warning Experience(IWE) Model

### 4.2.1 Sequence

The derived detailed design elements were considered for application by stage. These are organized in the table below.

*Table 13. Structuring the Behavioral Sequence for Warning Design*

| Sequence | Design Elements | Category | Distance | Design Considerations | Related Research Content | Researchers (Year) |
|---|---|---|---|---|---|---|
| **Encounter** | Proximity, luminance change | Conspicuity | Long distance | Before entering the hazard zone, utilize background change and luminance contrast | The user's first physical encounter with the warning stimulus functions as a condition for spatial awareness and attention induction | Endler (1991); Caro (2005) |
| **Detection** | High-chroma, high-brightness contrast, edge | | | High-contrast visual stimuli and clear edge placement strategy required for quick visual detection | In early visual detection, edge and color contrast are key factors in attracting attention | Stevens & Cuthill (2006); Merilaita et al. (2017) |
| **Identification** | Repetitive patterns, shapes, meaning-focused visual expressions | | Before entering close distance | Use of simplicity and repetition in visual information to induce quick and accurate semantic interpretation | The identification stage focuses on interpreting the meaning of the warning and inducing memory-based responses | Guilford (1989); Rowe & Halpin (2013) |
| **Avoidance Decision** | Warning enhancement, amplified patterns, color change based on distance | Distinctiveness | Close distance entry stage | Design a warning intensity stage that adjusts the strength of visual stimuli according to user proximity | Visual stimuli are gradually intensified to induce avoidance behavior in users | Tullberg et al. (2005); Honma et al. (2015) |
| **Avoidance Action** | Color inversion, motion amplification, warning animation | Conspicuity + Distinctiveness | Close distance | Drastic changes in color, shape, or animation expression are required to trigger immediate reaction | Dramatic visual change is necessary to induce avoidance behavior | Umbers & Mappes (2015); Stevens (2007) |
| **Feedback** | Visual feedback, return to stable state | | | Visual stabilization design is needed for return to original state after user compliance with warning | Post-warning recovery and promotion of follow-up learning about the same warning | Wogalter et al. (2015); Goldstein & Brockmole (2016) |

### 4.2.2 Diagrammatic Representation

The improved warning model incorporates four core features. First, at long distances—prior to direct exposure to danger—it emphasizes conspicuity by employing high-chroma and high-luminance contrast to facilitate early recognition and initiate avoidance responses. Second, at close range, it emphasizes distinctiveness by modulating visual stimuli such as color shifts and pattern amplification to segment warning levels and guide specific user actions. Third, design elements are differentiated by distance based on conspicuity and distinctiveness, and are contextually adapted to environmental factors such as luminance and background complexity. Fourth, upon resolution of danger or task completion, visual feedback is provided to signal state transition, supporting cognitive closure and user reassurance.

The model is diagrammatically illustrated as follows.

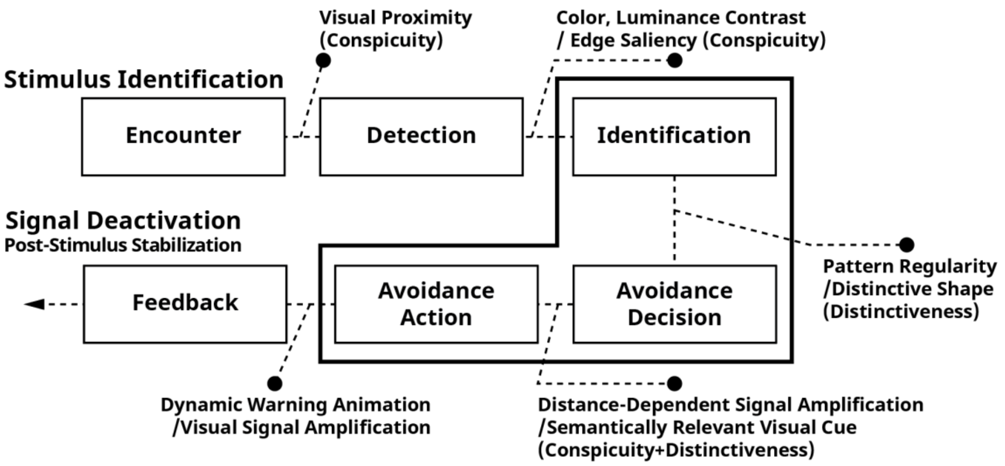



*Figure 6. integrated Warning Experience(IWE) Model*

# 5 Conclusion

## 5.1 Summary of the Study

This study is a theoretical inquiry aimed at addressing the limitations of existing user warning models through the application of biological warning expression strategies. First, by comparing the Predation Sequence with the Communication–Human Information Processing (C-HIP) model, functional parallels in warning reception were identified, and structural deficiencies in current design models were derived. Second, visual components such as color contrast, brightness, repetitive patterns, and shape transformation were extracted from biological strategies, and their practical relevance was validated through accident analyses involving cognitively vulnerable populations. Third, by focusing on the cognitive transition from detection to identification, visual warning elements were categorized by viewing distance and integrated into a user-centered safety design warning model, leading to the proposal of a new model that synthesizes conspicuity and distinctiveness.

The theoretical contributions are as follows. First, the study introduces the concept of distinctiveness to complement the traditional emphasis on conspicuity, enhancing user interpretation and behavioral response. In doing so, it also examined conditions that reduce visibility, such as camouflage, to identify perceptual factors that hinder conspicuity and distinctiveness. Second, it offers a biologically grounded framework for stage-specific visual design based on distance perception. Third, it incorporates visual contrast with background and feedback mechanisms into warning models, addressing gaps in existing approaches. Fourth, it foregrounds perceptual challenges faced by cognitively vulnerable groups and presents a warning framework applicable to both HRI and industrial environments.

Ultimately, This study redefined visual warning design not as a signal intensity–driven approach, but as a cognitively grounded process that considers the interplay between conspicuity and distinctiveness, emphasizing the need for warning design refined by perceptual conditions such as viewing distance and contextual factors. Accordingly, it provides a foundational framework for integrated warning strategies and suggested a structural reform direction for conventional user warning models.

### 5.2 Limitations of the Study

This study theoretically structured a visual-centered warning design framework by integrating biological warning strategies with cognitive models. However, as a preliminary theoretical proposal, it is limited by the absence of user-based experiments or quantitative validation. First, the distance-segmented design logic based on conspicuity and distinctiveness—though derived from biological theory and case analysis—lacks empirical verification of perceptual thresholds and behavioral effects. Second, the assumption that mimicry-based warning cues lead to consistent user recognition remains untested. Third, by focusing on the cognitive transition from detection to identification, visual warning elements were categorized by viewing distance and integrated into a user-centered safety design warning model, leading to the proposal of a new framework that synthesizes conspicuity and distinctiveness.

### 5.3 Future Research Directions

To validate the practical effectiveness of biologically inspired warning strategies, this study proposes four empirical directions. First, a color contrast model incorporating conspicuity and distinctiveness should be developed and tested through behavioral response experiments, enabling quantitative assessment of cognitive efficiency and avoidance induction across distance ranges. Second, real-time eye-tracking and luminance detection can be used to evaluate gaze behavior in context-rich environments, supporting the development of adaptive warning interfaces responsive to environmental conditions. Third, a toolkit integrating derived visual elements and biological strategies may assist in the automated generation of warning designs, with accompanying user protocols to support practical implementation. Fourth, research should extend beyond visual-only modalities to include multimodal cues—auditory, tactile, and motion-based—thus informing the development of comprehensive, sensory-integrated warning systems applicable to industrial and public settings.

## References


Allen, J. A. (1988). Frequency-dependent selection by predators. *Philosophical Transactions of the Royal Society of London.* Series B, Biological Sciences, 319(1196), 485–503.

ANSI Z535.1-2022. (2022). Standard for safety colors. *American National Standards Institute.*

Barnett, J. B., &Cuthill, I. C. (2015). Distance-dependent defensive coloration*. Current Biology*, 24(24), R1157–R1158.

Barnett, J. B., Cuthill, I. C., &Scott-Samuel, N. E. (2017). Distance-dependent pattern blending can camouflage salient aposematic signals. *Proceedings of the Royal Society B: Biological Sciences*, 284, 20170128.

Beusekom, M., Land-Zandstra, A., Bos, M., Broek, J., &Guchelaar, H. (2016). *Pharmaceutical pictograms for low-literate patients:* Understanding, risk of false confidence, and evidence-based design strategies. Patient Education and Counseling, 100(5), 966–973.

Bae, D. W. (2021, May). Dramatic rescue of deaf people after 6 hours of fire. *UBC*. http://web.ubc.co.kr/wp/archives/89131

Bruce, V., Green, P. R., &Georgeson, M. A. (2003). *Visual perception (4th ed.).* Psychology Press.

Caro, T. (2005). Antipredator defenses in birds and mammals. *University of Chicago Press*.

Chapanis, A. (1994). Hazards associated with three signal words and four colours on warning signs. *Ergonomics*, 37(2), 265–275.

Chiao, C. C., Chubb, C., &Hanlon, R. T. (2015). A review of visual perception mechanisms that regulate rapid adaptive camouflage in cuttlefish. *Journal of Comparative Physiology A*, 201(9), 933–945.

Clarke, B. (1962). Natural selection in mixed populations of two polymorphic snails. *Heredity*, 17, 319–345.

Cott, H. B. (1940). Adaptive coloration in animals. *Methuen &Co.*

Cuthill, I. C., &Székely, A. (2009). Coincident disruptive coloration. *Philosophical Transactions of the Royal Society B:* Biological Sciences, 364(1516), 489–496.

Dong-A Science. (2017, December 14). Fatal track worker accident at Onsu Station. https://dongascience.com/news.php?idx=20809

Edmunds, M. E. (1974). Defence in animals: A survey of anti-predator defences. *Longman.*

Edworthy, J., &Hellier, E. (2006). Complex nonverbal auditory signals and speech warnings. In M. S. Wogalter (Ed.), Handbook of warnings. CRC Press.

Endler, J. A. (1991). Interactions between predators and prey. In J. R. Krebs &N. B. Davies (Eds.), *Behavioural ecology* (3rd ed., pp. 169–196). Blackwell.

E. Bruce Goldstein &Brockmole, J. (2016). *Sensation and perception* (10th ed.). Cengage.

Fisher, R. A. (1930). The genetical theory of natural selection. Clarendon Press.

Golding, Y. C., &Edmunds, M. (2000). Behavioural mimicry of honeybees (Apis mellifera) by droneflies (Diptera: Syrphidae: Eristalis spp*.). Proceedings: Biological Sciences*, 267(1446), 903–909.

Gosliner, T. M., Behrens, D. W., &Valdés, Á. (2008). Indo-Pacific nudibranchs and sea slugs: A field guide to the worlds most diverse fauna. Sea Challengers Natural History Books.

Graham, N. V. S. (1989). Visual pattern analysers. Oxford University Press.

Greenwood, J. J. D. (1985). Frequency-dependent selection by seed-predators. *Oikos*, 44(1), 195–210.

Guilford, T., &Dawkins, M. S. (1989). Search image versus search rate: Two different ways to enhance prey capture. *Animal Behaviour*, 37(1), 163–165.

Hailman, J. P. (1977). Optical signals: Animal communication and light. Indiana University Press.

Halpin, C. G., Skelhorn, J., &Rowe, C. (2008). Being conspicuous and defended: Selective benefits for the individual. *Behavioral Ecology*, 19(5), 1012–1017.

Honma, A., Mappes, J., &Valkonen, J. (2015). Warning coloration can be disruptive: Aposematic marginal wing patterning in the wood tiger moth. Ecology and Evolution, 5.

ISO 3864-1. (2011). Graphical symbols—Safety colours and safety signs—Part 1: Design principles for safety signs and safety markings. International Organization for Standardization.

JSA - JIS Z 9103. (n.d.). Graphical symbols—Safety colours and safety signs—Part 4: Colorimetric and photometric properties of safety sign materials. Japanese Standards Association.

Kim, S. G. (2003). Language and social integration of persons with disabilities. Publishing Special Education.

Ko, H. J., &Kim, K. M. (2021). A study of the deaf experiences with cochlear implants: Focusing on the deaf who do not use cochlear implants. *Journal of Disability and Welfare*, 52, 165–197.

KS A ISO 3864-1. (2016). Graphical symbols—Safety colours and safety signs—Part 1: Design principles for safety signs and safety markings. Korean Agency for Technology and Standards.

Lee, J. W., &Kim, Y. S. (2011). A study on the effects of socio-economic characteristics of people with hearing impairment on the occurrence of information gap: Focused on the mediating effects of literacy. *Journal of Rehabilitation Research*, 15(4), 159–182.

Levin, B. R. (1988). Frequency-dependent selection in bacterial populations. *Philosophical Transactions of the Royal Society of London*. Series B, Biological Sciences, 319(1196), 459–472.

Maldonado, H. (1970). The deimatic reaction in the praying mantis Stagmatoptera biocellata. *Zeitschrift für Vergleichende Physiologie*, 68, 60–71.

María Arenas, L., Walter, D., &Stevens, M. (2015). Signal honesty and predation risk among a closely related group of aposematic species. *Scientific Reports*, 5, 11021.

Martin Stevens. (2007). Predator perception and the interrelation between different forms of protective coloration. *Proceedings of the Royal Society B: Biological Sciences*, 274, 1457–1464.

Mayhorn, C. B., Wogalter, M. S., &Shaver, E. F. (2004). What does code red mean? *Ergonomics in Design*, 12(4), 12.

Merilaita, S., &Ruxton, G. (2007). Aposematic signals and the relationship between conspicuousness and distinctiveness. *Journal of Theoretical Biology*, 245, 268–277.

Merilaita, S., Scott-Samuel, N. E., &Cuthill, I. C. (2017). How camouflage works. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 372(1724), 20160341.

Merilaita, S., Tuomi, J., &Jormalainen, V. (1999). Optimization of cryptic coloration in heterogenous habitats. *Biological Journal of the Linnean Society*, 67(2), 151–161.

Michael S. Wogalter. (2006). Purposes and scope of warnings. In M. S. Wogalter (Ed.), Handbook of warnings (pp. [page range]). Lawrence Erlbaum Associates.

Oh, B., &Kang, S. (2008). Information design textbook. Ahn Graphics Ltd.

O'Donald, P., &Majerus, M. E. (1988). Frequency-dependent sexual selection. *Philosophical Transactions of the Royal Society B:* Biological Sciences, 319(1196), 571–586.

Olofsson, M., Eriksson, S., Jakobsson, S., &Wiklund, C. (2012). Deimatic display in the European Swallowtail butterfly as a secondary defence against attacks from great tits. *PLOS ONE*, 7(10), e47092.

Osorio, D., &Srinivasan, M. V. (1991). Camouflage by edge enhancement in animal coloration patterns and its implications for visual mechanisms. *Proceedings of the Royal Society B: Biological Sciences*, 244, 81–85.

Owen, D. F., &Whiteley, D. (1989). Evidence that reflexive polymorphisms are maintained by visual selection by predators. *Oikos*, 55(1), 130–133.

Partridge, L. (1988). The rare-male effect: What is its evolutionary significance?. *Philosophical Transactions of the Royal Society B:* Biological Sciences, 319(1196), 525–539.

Penacchio, O., Lovell, P., Sanghera, S., Cuthill, I. C., Ruxton, G. D., &Harris, J. M. (2015). Countershading camouflage and the efficiency of visual search. *Perception*, 44(10), 1240.

Rowe, C., &Halpin, C. G. (2013). Why are warning displays multimodal? *Behavioral Ecology and Sociobiology*, 67(9), 1425–1439.

Ruxton, G. D., Franks, D. W., Balogh, A. C. V., &Leimar, O. (2008). Evolutionary implications of the form of predator generalization for aposematic signals and mimicry in prey. *Evolution*, 62(11), 2913–2921.

Seymoure, B., &Aiello, A. (2015). Keeping the band together: Evidence for false boundary disruptive coloration in a butterfly. *Journal of Evolutionary Biology*, 28(5).

Shapley, R., &Lennie, P. (1985). Spatial frequency analysis in the visual system. *Annual Review of Neuroscience*, 8, 547–581.

Sherratt, T. N., &Beatty, C. D. (2003). The evolution of warning signals as reliable indicators of prey defense. *American Naturalist*, 162(4), 377–389.

Shine, R. (2008). Function and evolution of the frill of the frillneck lizard, Chlamydosaurus kingii (Sauria: Agamidae). *Biological Journal of the Linnean Society*, 40(1), 11–20.

Smith, S. M. (1975). Innate recognition of coral snake pattern by a possible avian predator. *Science*, 187(4178), 759–760.

Son, J., &Yi, E. (2018). A study on a warning pictogram system for the hearing-impaired: Focusing on disaster and safety accident situations. *Archives of Design Research*, 31(3), 151–163.

Stevens, M., &Cuthill, I. C. (2006). Disruptive coloration, crypsis and edge detection in early visual processing. *Proceedings of the Royal Society B: Biological Sciences*, 273(1598), 2141–2147.

Stevens, M., &Merilaita, S. (2009). Defining disruptive coloration and distinguishing its functions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1516), 481–488.

Stevens, M., Cuthill, I. C., Párraga, C. A., &Troscianko, T. (2006). The effectiveness of disruptive coloration as a concealment strategy. In J.-M. Alonso, S. Macknik, L. Martinez, P. Tse &S. Martinez-Conde (Eds.), *Progress in brain research* (Vol. 155, pp. 49–65). Elsevier.

Stevens, M., &Ruxton, G. D. (2012). Linking the evolution and form of warning coloration in nature. *Proceedings of the Royal Society B: Biological Sciences*, 279, 417–426.

Stobbe, N., &Schaefer, H. M. (2008). Enhancement of chromatic contrast increases predation risk for striped butterflies. *Proceedings of the Royal Society B: Biological Sciences*, 275(1642), 1535–1541.

Stuckert, A. M., Venegas, P. J., &Summers, K. (2013). Experimental evidence for predator learning and Müllerian mimicry in Peruvian poison frogs (Ranitomeya, Dendrobatidae). *Evolutionary Ecology*, 28(4).

Symula, R., Schulte, R., &Summers, K. (2001). Molecular phylogenetic evidence for a mimetic radiation in Peruvian poison frogs supports a Müllerian mimicry hypothesis. *Proceedings of the Royal Society B: Biological Sciences*, 268(1484), 2415–2421.

TIME. (2016, August 23). Daniel Harris shooting—North Carolina. TIME. https://time.com/4464444/deaf-man-police-shooting-daniel-harris/

Todd, P. A., Phua, H., &Toh, K. B. (2015). Interactions between background matching and disruptive colouration: Experiments using human predators and virtual crabs. *Current Zoology*, 61(4), 718–728.

Tullberg, B. S., Merilaita, S., &Wiklund, C. (2005). Aposematism and crypsis combined as a result of distance dependence: Functional versatility of the colour pattern in the swallowtail butterfly larva. *Proceedings of the Royal Society B: Biological Sciences*, 272, 1315–1321.

Umbers, K. D. L., &Mappes, J. (2015). Postattack deimatic display in the mountain katydid, Acripeza reticulata. Animal Behaviour, 100, 68–73.

Wood, V. T., &Weisman, R. A. (2003). A HOLE IN THE WEATHER WARNING SYSTEM: Improving Access to Hazardous Weather Information For Deaf and Hard of Hearing People. *Bulletin of the American Meteorological Society*, 84(2), 187–194.

Wogalter, M. S., Laughery, K. R., &Mayhorn, C. B. (2012). Warnings and hazard communications. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (4th ed., pp. 868–894). Wiley.

Wogalter, M. S., Mayhorn, C. B., &Zielinska, O. A. (2015). Use of color in warnings. In A. J. Elliot, M. D. Fairchild, &A. Franklin (Eds.), *Handbook of color psychology* (pp. 377–400). Cambridge University Press.

Wogalter, M. S. (Ed.). (2006). Handbook of warnings (1st ed.). CRC Press.

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