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GESTALT THEORY, DOI 10.2478/gth-2023-0023
© 2023 (ISSN 2519-5808); Vol. 45, No. 3, 301–311

Original Contribution - Originalbeiträge

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Enhanced distractor filtering in habituation contexts: Learning to ignore is easier in familiar environments

Introduction

Perhaps some of you might find yourselves familiar with the following scenario: imagine attending a musical event, completely immersed in the live performance unfolding on the stage. Suddenly, a bright light captures your attention. As you turn towards the source, you notice a man holding a lit lighter with his arm raised over the crowd. It strikes you that this person, embodying the final nostalgic remnants of a past generation, stands out amidst the modern audience. In today's evolved social landscape, such displays seem out of place; the gentleman's behavior has slipped out of context. In its place, a different and rather distracting trend has emerged: the incessant use of cellphones by the audience. While contemplating these reflections, you might gradually come to realize that most of the crowd is illuminated by the moving lights emanating from multiple cellphones, a sight you had previously disregarded, although the cold, bright screens of these cellphones are no less luminous than the lighter the man is holding. In this situation, your attention would be captured not solely by the salience of the surrounding stimuli, but rather by the intricate interplay between these stimuli and their contextual environment. This contribution delves into the significance of context in shaping how our cognitive systems learn to attend to or ignore environmental stimuli - an aspect often underestimated and undervalued. Before proceeding, it is important to acknowledge the multifaceted nature and extensive spectrum of definitions associated with the term 'context.' Mood, physiological states, and social contours represent only a fraction of the diverse examples encompassed by this concept. Given its broad nature, fully addressing its spectrum within the confines of the present manuscript is beyond our scope. Consequently, our considerations will specifically narrow down to the visual information, such as layout and surroundings, pertinent to both relevant and irrelevant visual stimuli.

Habituation of the orienting response

Regardless of whether you are acquainted with the preceding scenario or not, it is highly likely that your attention would be captured by a sudden and salient stimulus, prompting it to shift from its current focus. Numerous studies have demonstrated that physically salient stimuli generate a priority signal, automatically capturing attention. For example, a sudden and transient change in brightness in a circumscribed section of the visual field, referred to as a visual abrupt onset, is a highly salient stimulus that captures attention (e.g. Yantis & Jonides, 1990), enhancing the readiness for processing new information while disrupting the current attentional focus. This ambivalence - the advantage of prioritizing potentially crucial information and the drawback of distraction from ongoing goals - can be reconciled through a learning mechanism referred to as habituation. This mechanism allows, based on past experiences, the ability to ignore irrelevant and repetitive stimuli, even if they are inherently salient.

The notion of habituation traces its origins back to ancient times, as evidenced in Aesop's fables from the 5th century BC, such as the tale of the fox and the lion. Habituation, often regarded as the most basic form of learning, involves the gradual decrease in responses to irrelevant stimuli with repeated exposure. Notably, this effect is not a result of fatigue or sensory adaptation (Harris, 1943; Thompson & Spencer, 1966). This phenomenon has been observed across diverse organisms, ranging from unicellular amoebas to humans (Boisseau et al., 2016; Thompson, 2009), and for various types of responses (Barry, 2009; Codispoti et al., 2016), although it was originally explored in the domain of the orienting reflex (OR) exhibited by organisms in response to novel sensory stimuli (Pavlov, 1927). An evolutionary perspective can elucidate the diffusion of this learning mechanism. Considering that attentional resources are limited and must be allocated discerningly among the multitude of stimuli inundating our senses in any given moment and environment, this mechanism becomes crucial. It serves to augment cognitive performance and, significantly, contributes to survival.

Recent studies have shown that humans' covert attentional capture habituates to visual abrupt onsets (De Tommaso & Turatto, 2023; Turatto, 2023; Turatto & Pascucci, 2016; Turatto & Valsecchi, 2022). In a typical experiment, participants are required to indicate a particular feature of a target (e.g., its orientation) appearing in one of several placeholders. Just before the appearance of the target, a distractor is introduced in certain trials, consisting in the brief brightening of one of the placeholders. Performance analysis is carried out over a temporal continuum, revealing that participants exhibit slower responses in trials where the distractor is present compared to trials where the distractor is absent. This disparity in response time is interpreted as the consequence of the attentional capture induced by the presence of the distractor. Notably, this attentional cost diminishes progressively as the experiment progresses, signifying a reduction in the attentional response with repeated exposure to the distractors (see Figure 1).

Within the realm of contemporary theories concerning visual attention, habituation theories, refined through concurrent research trajectories (e.g., Sokolov, 1960),

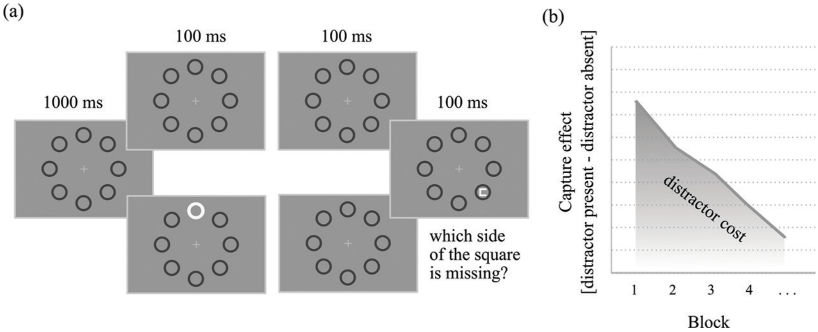

Fig. 1. (a) Schematic representation of a typical task administered to investigate habituation of visual attentional capture. The upper series of events depicts the distractor-absent condition, the lower represents the distractor-present trials. (b) Theoretical trend of the typical results of the task: as the experiment unfolds, the initial cost on performance attributed to the presence of the distractor diminishes, indicating habituation.

offer valuable insights despite often being overlooked (Turatto, 2023). Notably, these theories exhibit significant parallels and intersections. For example, a prevalent acknowledgment now exists regarding the profound impact of past repeated exposure, termed as "selection history," on our processing of visual stimuli. This notion fundamentally reshaped the longstanding theoretical dichotomy of bottom-up and top-down control of visual attention (Awh et al., 2012).

Selection history has been related to various effects, including but not limited to past search experiences (Shiffrin & Schneider, 1977), contextual cueing (Chun & Jiang, 1998), priming (Maljkovic & Nakayama, 1994), statistical learning of target and distractor location (Ferrante et al., 2018; Wang & Theeuwes, 2018), and its association with motivational aspects such as reward or punishment (Anderson et al., 2011; Anderson & Britton, 2020; De Tommaso et al., 2019; Della Libera & Chelazzi, 2009; Le Pelley et al., 2015). The wide-ranging application of these effects has led some researchers to posit that selection history has become a somewhat elusive concept within attention literature (Anderson et al., 2021). While the precise relationship between selection history and habituation remains to be fully elucidated, their shared reliance on previous experiences for learning and their documented impacts on visual attention are evident. Consequently, an integrative approach involving these concepts, along with other forms of statistical learning, is advisable to achieve a more comprehensive understanding of cognitive processing in this domain.

The mechanism by which habituation is achieved is extensively described by models that integrate different factors (Rankin et al., 2009; Schmid et al., 2015). For example, the dual-process theory devised by Groves and Thompson (1970) describes a basic neuro-physiological mechanism based on mere repetition, accounting for the capacity for this form of learning in organisms equipped with an apparently unsophisticated nervous system (e.g. Carew et al., 1972).

The Stimulus-Model Comparator Theory, proposed by Sokolov (1960, 1963), involves instead higher-order cognitive processes. Sokolov developed this theory based on his observations of ORs, often quantified through event related potentials (ERPs) or other physiological responses. According to this model, a novel sensory input triggers a behavioral response. However, through repeated exposure, an internal representation of the stimulus is formed. Subsequent inputs are compared to this internal representation. If an input matches the representation, in the response is inhibited, giving rise to habituation. Notably, this model also elucidates response recovery. If the input does not align with the internal representation, the inhibition is lifted, and the response is reinstated. This prediction is supported by a study by De Tommaso and Turatto (2019), which replicated the findings by Vatterott and Vecera (2012), in which participants were asked to find a specific figure (a circle) among others and report the orientation of the line inscribed within it. In certain trials, an additional figure, distinguished by a different color from the rest (a color singleton), was introduced. Generally, findings indicate that trials featuring such singletons exhibit slower response times compared to trials without them. However, this performance cost diminishes with increasing experience, as postulated by the habituation hypothesis. Remarkably, when the characteristics of the singleton are altered, such as its color, the response to that stimulus shows a clear recovery. Notably, in this study habituation and its characteristics are reported for color-singleton distractors. Despite the processing of static (color singletons) and dynamic (abrupt onsets) visual discontinuities may not necessarily conform (Ruthruff et al., 2020), habituation to static discontinuities has been discussed by other studies (Valsecchi & Turatto, 2021). Furthermore, the phenomenon of response recovery extends to instances where other attributes of the habituated stimuli changes, including their temporal characteristics. A study by Turatto and De Tommaso (2022) demonstrated that if the same onset distractor, to which participants had already habituated, occurs slightly outside the expected temporal window, it triggers a notable response recovery.

The interplay between habituation and context

The habituation process relies on the refinement of mental templates, honed through repeated exposure to discrete stimuli. As previously mentioned, in some instances even a slight deviation in features from an otherwise identical stimulus can reinstate the habituated response. However, this delicate computation between external stimuli and internal representation extends beyond the discrete stimuli, as it takes into account another seemingly unrelated yet integral aspect of the global stimulation: the context in which the stimulation occurs. Accordingly, Allan R. Wagner developed a model that defines the interplay between context and habituation based on an associative learning mechanism (Konorski, 1967; Wagner, 1976, 1979). According to his gnostic-unit theory, the context triggers anticipation of the upcoming stimulus through an association formed through repeated exposure to the stimulus within its context. This association, stored in long-term memory (LTM), transforms the context into a predictor of the occurrence of the stimulus to be ignored, as the context retrieves in short-term memory (STM) the stimulus representation. It is worth to emphasize that the central concern here is not habituation to contextual information, which undeniably presents an intriguing avenue for exploration. Instead, the focus lies on elucidating the role of context within which habituation occurs and how, within this framework, it aligns with theories of associative learning.

In the realm of attentional capture by visual stimuli, there are at least two studies underscoring the influence of context on habituation. In a study conducted by Turatto et al. (2018), the authors hypothesized that the covert attentional response to a stimulus onset, once diminished through habituation, would recover if participants were not exposed to the onset for a period while performing the task in the same context. The authors posited that, in line with Wagner's model, this period of *extinction* would weaken the association between the context and the previously encountered distractor. The context would gradually become a predictor of the absence of the distracting onset. Upon reintroducing the onset in a test phase two days later, the results clearly indicated a response recovery, reverting participants' performance back to the level observed at the beginning of the experiment.

In a separate study conducted by Turatto et al. (2019), the researchers directly manipulated the context by altering the background image of the task. The underlying hypothesis remained consistent: if the context retrieves the presence of the distractor due to their association, the response will remain habituated as long as the context remains unaltered, as the distractor would be fully anticipated. Conversely, if the context changes, response recovery would occur. The study involved two distinct groups of participants, and the results unequivocally confirmed the stated predictions.

More recently, De Tommaso et al. (2023) replicated the findings of Turatto et al. (2018) by refining the experimental paradigm. In the study, the authors designed a new procedure centered around an omission phase, during which participants were deliberately not exposed to the distractor. This omission phase, conducted on a second session the following day, was situated between a training phase (day 1) and a test phase (day 2), where the distractor could appear in a subset of the trials. Importantly, omission was implemented in the same context for one group (Extinction) and in a different context for a second group (Control).

Context manipulation was achieved by changing the background image during the task (see Figure 2, panel a). Similar to Turatto et al. (2018), it was expected the distractor's impact to decrease during the training phase and then recover in the test phase for the Extinction group, where omission took place in the same consistent context throughout the experimental sessions. Conversely, the Control group, in which distractor omission occurred in a different context, was not expected to exhibit any response recovery; this group was anticipated to maintain the same response level observed at the end of the training phase (see Figure 2, panel b).

As anticipated, when participants encountered the distractor after omission, only those in the Extinction group displayed an increased performance cost, while the performance of participants in the Control group remained unchanged. Wagner's model aligns seamlessly with the observed pattern of results: unlike the Extinction group, where the association between the context and the distractor presence degraded, the Control group maintained an unchanged context-distractor association during omission because it occurred in a different context. Consequently, upon encountering the distractor again, the original context retained its predictive property about the presence of the distractor, which, in turn, continued to be ignored.

How contexts influence habituation to brand-new distractors

Current evidence suggests that mechanisms that lead to distractor rejection are not solely dependent on stimulus features but are also influenced by the context in which the stimulus is encountered (Chiandetti & Turatto, 2017; Dissegna et al., 2021; Turatto et al., 2018, 2019). To explain the phenomenon, we have

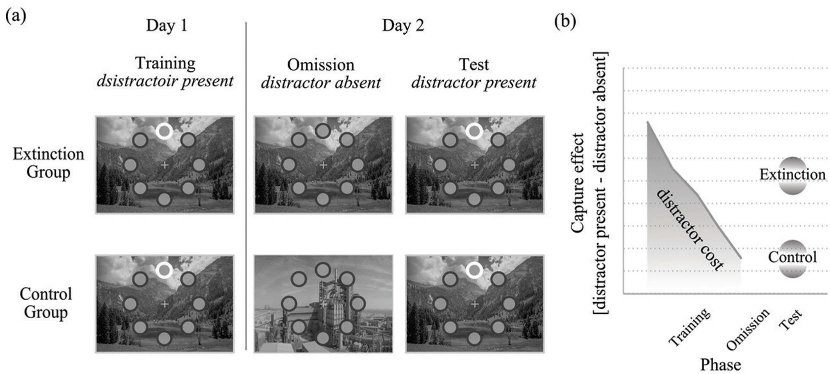

Fig. 2. (a) Schematic representation of the experimental procedure investigating the influence of context on habituation to onset's capture through an omission phase. (b) Theoretical trend of the results: the reduced cost of distractor presence is maintained for the Control Group in which distractor omission occurred in a different context, while response recovery is manifested for the Extinction Group in which omission occurred in the same context. See De Tommaso et al. (2023) for details.

reported Wagner's model whereby the context pre-activates the stimulus that has been learned to be ignored due to their association (Konorski, 1967; Wagner, 1976, 1979). At this stage, one might delve deeper into the question of whether contexts possess the capacity to influence not only familiar stimuli but also entirely novel stimuli that have not been previously encountered. This hypothesis aims to determine whether contexts have the capacity to evoke a general inhibitory response. In essence, the question centers on whether the ability to ignore new distracting stimuli becomes more effortless within contexts where we have previously learned to inhibit other stimuli.

De Tommaso et al. (2023) explored the influence of context of habituation in participants' ability to filter onset distractors that were never encountered before. The experiment, spanning two sessions over consecutive days, involved participants performing a visual detection task perturbed, in a subset of the trials, by a sudden onset that consistently appeared in the same position on the display. Subsequently, during the second session, participants were divided into two groups: one group performed the task in the same context as the first session (referred to as the Inhibitory Context group), while the other group carried out the task in a different context (referred to as the Different Context group). During the second session, the task remained consistent for both groups, but the onset distractor, when present, appeared in a distinct position on the display (see Figure 3, panel a).

The results indicated that by the end of the first session, participants had habituated to the distractor, as evident from the significant reduction in the performance cost associated with its presence. At the start of the subsequent day, it was anticipated that the new distractor would trigger a comparable recovery of capture in both groups, given that onset filtering relies on its expected position (De Tommaso & Turatto, 2023; Turatto & Valsecchi, 2022; Valsecchi & Turatto, 2022).

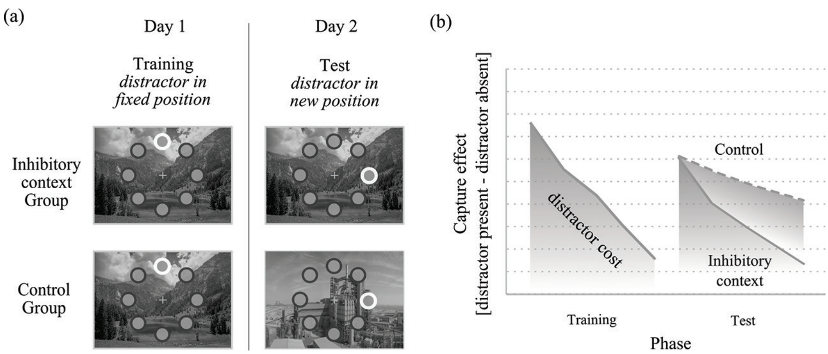

Fig. 3. (a) Schematic representation of the experimental procedure exploring the role of context of habituation to filter new onset distractors. (b) Theoretical trend of the results: both the Inhibitory context and the Control group habituate and recover the response to the distractors comparably, but the Inhibitory context group is more efficient in rejecting the new distractor. See De Tommaso et al. (2023) for details.

However, a key prediction was that the Inhibitory Context group, which encountered the new distractor in the same context where they had habituated the day before, would exhibit more efficient habituation to the new distractor compared to the Different Context group.

The results supported both predictions: habituation on the first day and recovery of capture on the second day were evident in both groups, yet crucially, the Inhibitory Context group demonstrated a more efficient rejection of the new distractor. These findings were interpreted as indicative of the context's acquired ability not only to predict a specific stimulus to be ignored but also to facilitate a broader form of response inhibition. In other words, participants in the Inhibitory Context group found it easier to reject the new distractor because the context retained its ability to generate a distractor expectation in general, which extended to a stimulus appearing in a new position (see Figure 3, panel b). This generalization aligns with existing evidence, underscoring that habituation to visual onsets encodes both local and global components of irrelevant stimuli (De Tommaso & Turatto, 2023).

Concluding remarks

Processing irrelevant information imposes a superfluous burden on the already limited attentional resources, serving as an unnecessary distraction and potentially posing a threat when more pertinent information demands our focus. The brains of humans and other animals are equipped with neural structures that enable the enhancement of relevant information and the ability to ignore irrelevant information (Klink et al., 2023; Marini et al., 2016). Habituation mechanisms capitalize on repetition to construct a comprehensive model of the external world, utilizing it as a tool to overcome the challenges posed by the orienting reflex. As previously described, internal representations do not merely comprise a sum of individual elements within the environmental stimuli. Instead, they include a nuanced interplay between stimuli and their respective contexts, enabling the generation of predictions (den Ouden et al., 2012; Friston, 2005; Itti & Baldi, 2009; Sokolov, 1960, 1963; Summerfield & Egner, 2009; Wagner, 1976).

For readers familiar with the concert scenario, they discovered they were no longer accustomed to the sight of lighters in the audience, possibly indicating the extinction of their inhibitory response towards that stimulus, which subsequently captured their attention. In contrast, cellphones, being prevalent distractions in concert settings, did not even register in their awareness from the beginning. This lack of notice likely stemmed from the ubiquity of cellphones in such environments. However, some readers may anticipate regaining their attention to cellphones soon, as this would signify that these devices have become out of context, prompting a renewed response.

Short summary
Habituation mechanisms play a pivotal role in enabling organisms to filter out irrelevant stimuli and concentrate on essential ones. Through repeated exposure, the brain learns to disregard stimuli that are irrelevant, effectively ceasing to respond to potentially distracting input. Previous studies have demonstrated that the orienting response to visual distractors disrupting visual detection tasks habituates as tasks progress and distractors are encountered repeatedly, as their initial interference diminishes. Theoretical models posit that this reduction is contingent upon the establishment of an internal representation of external stimuli. Moreover, further studies have indicated that habituation can be context-specific, suggesting that the mechanisms involved incorporate information about features of irrelevant stimuli that extend beyond their discrete characteristics. In this contribution, we further delved into the question of whether the context in which habituation occurs retains a general habituative capacity when a new, to-be-ignored stimulus is introduced. We discuss evidence indicating that the context in which habituation has already taken place facilitates the habituation process for a new stimulus. This suggests that it becomes easier to ignore new stimuli in contexts where we have already learned to disregard other stimuli, underscoring the intricate interplay between habituation, context, and attentional processes.
Keywords: habituation; attentional capture; context; associative learning; prediction.

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