Habituation (of attentional capture) is not what you think it is

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Abstract

Habituation represents a well-established form of learning in various neuroscience domains. However, cognitive psychologists working in the field of visual attention have largely overlooked this phenomenon. In this regard, I would like to argue that the reduction in attentional capture observed with repetitive salient distractors, and specifically abrupt visual onsets, could be attributed to habituation.

Three classic models of habituation, independently devised by Sokolov, Wagner, and by Thompson, will be presented and discussed in relation to the capture of attention. Of particular interest is the fact that Sokolov's model is governed by a prediction-error minimization principle, where a stimulus attracts attention to the extent that it violates the expected sensory input, which is anticipated on the basis of the previous history of stimulation. Hence, at least in humans, habituation is governed by high-order cognitive processes, and should not be confounded with peripheral sensory adaptation or fatigue. Furthermore, the cognitive nature of habituation is also attested by the fact that visual distractor filtering is context specific. In conclusion, as already suggested by others, I believe that researchers working in the field of attention should give more consideration to the notion of habituation, especially with regard to the control of stimulus-driven capture.

Public significance statements

The human brain is naturally equipped with neural mechanisms that allow a rapid orienting of attention toward novel salient stimuli that appear in the visual field. Such rapid orienting is an adaptive response because it allows a rapid inspection of potentially significant events. However, the brain must also be capable of ignoring a salient stimulus when it occurs in an iterative fashion, because otherwise the resulting repetitive orienting would be a dangerous distracting response. Here I discuss how habituation mechanisms offer an adaptive solution to this problem, as they allow the brain to learn to disregard salient albeit irrelevant events that are repeatedly encountered. Habituation of capture thus prevents continuous misallocations of attention, which could lead to dangerous distraction.

In 1988, Robert Rescorla published in the *American Psychology* a famous article entitled “Pavlovian conditioning: It is not what you think it is”, in which he explained why the general thinking about this form of associative learning was mistaken. In particular, and this is relevant for what it will be argued here, the key point stressed by Rescorla was that conditioning takes place only when there is a positive (or negative for inhibitory conditioning) *contingency* between the conditioned stimulus (CS) and the unconditioned stimulus (US), or in other words, when the CS is a reliable predictor of the US (Kamin, 1968; Rescorla, 1966). By contrast, the shared view at that time, as reported in many textbooks of psychology, was that Pavlovian conditioning merely required a simple paring between CS and US, namely a temporal *contiguity* between the two stimuli. This view, however, overlooked the key role played by *contingency*, which is defined by the statistical relation between CS and US, learned as the organism is exposed to their occurrences. Hence, Rescorla wanted to make clear that Pavlovian conditioning requires an act of cognition capable of capturing the statistical relations between the two events, and that conditioning is not a trivial mechanical process whereby a response shifts from the US to the CS when the former follows the latter (Kirsch et al., 2004).

Some decades later the issue raised by Rescorla about conditioning, habituation seems to still be affected by a similar misconception. In particular, in the attention-research community habituation, which reflects the fact that the organism responds progressively less to an iterative stimulation, is often seen and interpreted as a peripheral non-cognitive process, typically equated with sensory adaptation or motor fatigue. Indeed, in recent reviews on the mechanisms involved in the control of attentional capture habituation is presented, if any, only as a marginal process possibly contributing to the attenuation of the distracting impact of an irrelevant salient stimulus (e.g., Luck et al., 2021; van Moorselaar & Slagter, 2020). That cognitive scientists working in the field of attention may conceive habituation in this way is somewhat ironic, given that in research areas with much less cognitive vocation, like for instance in the neurobiology of learning, researchers largely acknowledge that habituation is a phenomenon reflecting the animal's ability *to learn to ignore* the irrelevant information. For example, as reported in an eminent review on the topic "*…habituation allows animals to filter out irrelevant stimuli and focus selectively on important stimuli…*" (Rankin et al., 2009), a description that, I shall notice, is very similar to the idea that cognitivists have about attention. Indeed, since the seminal work of Donald Broadbent attention is metaphorically and computationally described as a filter operating a selection on the incoming information (Broadbent, 1958). However, despite both habituation and attention refer to the notion of filtering, as a matter of fact habituation reflects the operation of a cognitive mechanism that controls the attention filter by preventing its mis-allocation toward an irrelevant repetitive stimulation (Cowan, 1988; Waters et al., 1977).

As a matter of fact, in addition to the orienting of attention different types of response can be subject to habituation, like for example the tap-withdrawal response in worms (Giles & Rankin, 2009), the mating preference in different animal species (Chiandetti & Turatto, 2019; Daniel et al., 2019), and the reward-reinforcing property (Aoyama & McSweeney, 2001; Lloyd et al., 2014). Hence, *natural selection* has found different ways or mechanisms, from molecular/cellular levels to the overt behavioral level, to reduce the organism's responsiveness to a repetitive stimulation.

Here, however, I will discuss only the phenomenon of habituation of attentional capture. Specifically, I will refer to the habituation of the exogenous orienting response elicited by a salient albeit irrelevant abrupt visual onset stimulus, hereafter called distractor, that is repeatedly encountered. This choice is also motivated by the fact that one of the most important theoretical model of habituation, developed by the Russian physiologist Evgeni Sokolov, specifically deals with the fading of the *orienting reflex* (OR) triggered by a repeatedly presented stimulus (Sokolov, 1960), and of which the orienting of covert attention is one of the various components (Sokolov, Nezlina, et al., 2002). Hence, in the attempt to emphasize the cognitive nature of habituation, first I will briefly outline its features (for more exhaustive descriptions see, Rankin et al., 2009; Thompson, 2009), and then I will present the three main theoretical models or theories of habituation. As it will emerge, at least two of them conceive habituation as resulting from mental processes like memory, learning, comparison and prediction (or expectation), which are often associated with high-level cognitive processes, at least in humans. I will therefore discuss why the reduced capture observed with a repeated visual onset distractor is not due to sensory adaptation or motor fatigue, but is indeed an instance of central filtering, namely of habituation. Notice that to speak of habituation of capture, or of habituation in general, it is not necessary that the capture response, or any response in general, is reduced to zero; rather it is sufficient that because of the repeated exposure to the distractor the initial level of capture is significantly reduced.

Before continuing, I would like to clarify three key aspects of this work. First, the primary goal is not to provide a comprehensive review or critique of the current literature on the neuro-cognitive mechanisms involved in distractor rejection. Instead, this work aims to offer a clearer understanding of the habituation phenomenon in relation to attentional capture. Second, while habituation is one potential mechanism for reducing unwanted capture, other mechanisms have also been proposed. Third, the available data suggest that habituation mechanisms can provide a straightforward explanation for the attenuation of capture observed with onset distractors, but other mechanisms may be more relevant for feature-singleton distractors.

The characteristics of habituation

With few exceptions, almost all types of responses that an organism is capable of can be subject to habituation (Barry, 2009), although some exceptions may exist (Bonetti et al., 2020). Regardless of the response being measured, habituation typically exhibits key features that were originally described by Thompson and Spencer (1966). These features, which have been observed across studies involving both humans and non-human animals and measuring physiological, motor, and electrocortical responses, are part of the OR (Barry, 2009). However, since the present study is concerned with the relationship between habituation and visual attention, I will briefly discuss how each of these features might apply to a cognitive response like the exogenous orienting of attention (Jonides, 1981), under the reasonable assumption that exogenous orienting attention towards a given stimulus or location is a mental activity or response that has a neural correlate, and can therefore be subject to habituation.

It should be noted that studies proposing the idea that attentional capture is subject to habituation have so far mainly addressed this phenomenon in relation to visual-onset distractors (e.g., Dukewich, 2009; Folk & Remington, 2015; Turatto & Pascucci, 2016; Valsecchi & Turatto, 2022), although some studies have also considered feature-singleton distractors (Allenmark et al., 2022; De Tommaso & Turatto, 2019; Won & Geng, 2020).

Characteristic #1: *Given that a particular stimulus elicits a response, repeated applications of the stimulus result in decreased response (habituation). The decrease is usually a negative exponential function of the number of stimulus presentations*.

In other words, repeated exposure to a salient distractor should lead to a reduction in the attentional capture response. This prediction has been supported by several studies investigating onset capture (Dukewich, 2009; Dukewich & Boehnke, 2008; Folk & Remington, 2015; Neo & Chua, 2006; Turatto, Bonetti, & Pascucci, 2018; Turatto et al., 2019; Turatto & Pascucci, 2016; Valsecchi & Turatto, 2022; Turatto & Valsecchi, 2022; but see Ruthruff et al., 2019). Note that whereas Turatto and his colleagues have reported habituation of onset capture in a paradigm where participants could fully focus their attention on the target position before the onset appearance (e.g., Pascucci & Turatto, 2015; Turatto & Pascucci, 2016; Turatto et al., 2018), two classic studies have reported that onsets do not capture focused attention (Theeuwes, 1991; Yantis & Jonides, 1990). It should be noted, however, that whether or not onsets capture fully focused attention is not central to the core topic discussed here, which concerns only habituation of capture by abrupt onsets, irrespective of the attentional status.

Characteristic #2: *If the stimulus is withheld, the response tends to recover over time (spontaneous recovery)*.

If an onset distractor is temporarily omitted after a habituation phase, capture is expected to recover, to some extent, when the distractor is re-introduced. To my knowledge only a few studies have tried this manipulation; however, the little evidence collected from studies where the distractor has been temporally omitted, and then re-introduced, is consistent with this prediction (e.g., Turatto, Bonetti, & Pascucci, 2018).

Characteristic #3: *If repeated series of habituation training and spontaneous recovery are given, habituation becomes successively more rapid (this might be called potentiation of habituation)*.

To the best of my knowledge, no attentional capture studies have tested this prediction. However, one would expect a faster rate of capture habituation each time the distractor is reintroduced after an omission phase.

Characteristic #4: *Other things being equal, the more rapid the frequency of stimulation, the more rapid and/or more pronounced is habituation*.

In classic habituation studies, the stimulus *temporal frequency* is defined by the number of stimuli presented per unit of time (seconds or minutes), which is determined by the inter-stimulus interval (ISI). What is typically found is that the higher the frequency (i.e., the shorter the ISI), the faster and/or more pronounced the habituation response is (Askew, 1970; Broster & Rankin, 1994; Davis, 1970; Geer, 1966; Thompson & Spencer, 1966). The term "faster" in the context of habituation refers to reaching the asymptotic level in fewer trials, but this characteristic may not be easily detected in attentional capture studies. It is important to note that in many attentional-capture paradigms, the distractor is not presented on every trial, but rather on a proportion of the total trials, with the distractor frequency expressed as the distractor rate or probability (but see Theeuwes, 1991, 1992). Demonstrating a faster rate of habituation for a higher-probability distractor compared to a lower-probability distractor may be problematic because the capture response is measured only indirectly, by considering the detrimental effect of the distractor presence on the time required to detect or discriminate the target element, as measured via response times (RTs). As discussed by Turatto and Valsecchi (2022), due to the RTs intrinsic variability the capture response (or distractor interference) is obtained by averaging a large number of trials, with the result that the fast descending part of the initial portion of the habituation function for a high-rate distractor could be masked.

There, is however, a direct relation between distractor *probability* and *frequency*, because all other conditions being equal the larger the number of trials in which the distractor is presented the higher also its temporal frequency of occurrence. Yet, any effect observed by manipulating the distractor probability is not necessarily caused by a change in the distractor temporal frequency. Indeed, we have recently shown that the amount of capture triggered by two distractors appearing with the same probability, but with different temporal frequencies was the same (Turatto & Valsecchi, 2022). This is not to say, however, that the distractor temporal frequency is in general irrelevant in determining the amount of capture, because it could become a factor when larger temporal frequency differences are considered, or when capture is tested with a different paradigm with respect to the classic additional-singleton or spatial-cueing tasks.

Characteristic #5: "*The weaker the stimulus, the more rapid and/or more pronounced is habituation. Strong stimuli may yield no significant habituation*".

I am not aware of any study that has manipulated the saliency of the same type of distractor (e.g., an onset singleton or a feature singleton) to see how this changes the corresponding habituation function, but the prediction is clear: more salient distractors should yield weaker habituation of capture.

Characteristic #6: "*The effects of habituation training may proceed beyond the zero or asymptotic response level*".

While learning is generally expressed by a change in the observable behavior, in fact since the seminal work of Blodgett (1929) on *latent learning* it is well known that learning can take place also in a concealed fashion, namely despite no observable changes in the overt behavior (Tolman & Honzik, 1930). Interestingly, this learning property seems to regard also habituation, as there is evidence showing that if the stimulation continues after the response has vanished or has reached a stable level of performance (i.e. the asymptote), then response recovery will be delayed as compared to a shorter training phase (Prosser & Hunter, 1936; Rankin & Broster, 1992). As for attentional capture, the prediction is that once habituation has reached an asymptotic level, continuing to present the distractor should delay the recovery of capture when the distractor is re-introduced after an extinction phase, or to put it differently, the amount of capture recovery should be weaker for the same extinction phase length.

Characteristic #7: "*Habituation of response to a given stimulus exhibits stimulus generalization to other stimuli*".

This characteristic refers to a general principle of learning, namely the fact that it can transfer, or generalize, from one condition (or stimulus) to a similar one. Clearly, whether or not generalization occurs is an empirical question, and depends on how much the organism perceives the two conditions of stimulation as being similar. By contrast, when there is no transfer learning is said to be specific. Habituation, like other forms of learning (e.g., conditioning and perceptual learning), can show either generalization or specificity, depending on the specific conditions. Specificity is attested by a more or less complete recovery of the habituated response when a new stimulus, or a variation in some parameters of the habituating stimulus is introduced (Broster & Rankin, 1994; Sharpless & Jasper, 1943; Steiner & Barry, 2014; Turk-Browne et al., 2008). As far as attention is concerned, we have recently found that observers can learn to ignore an onset when it appears at the predicted time, but that capture recovers when the same distractor is presented one second later, thus showing a time-specific habituation to visual onsets (Turatto & De Tommaso, 2022). Additionally, we have shown that the amount of oculomotor capture triggered by a sudden onset habituates across trials, but the reflexive saccadic response toward the distractor recovers when its color changes (Bonetti & Turatto, 2019). If, however, one would be willing to consider the possibility that the notion of habituation of capture can extend also to non-onset distractors (Allenmark et al., 2022; Geng et al., 2019), then the literature presents results that so far have shown both specificity and generalization of habituation, depending on the specific stimuli and procedure used (Won & Geng, 2020; Won et al., 2018, 2019). For example, Vatterott and Vecera (2012) found that the amount of capture elicited by a color singleton diminished with practice, but also that capture recovered completely when the distractor color changed, thus showing a case of specificity. However, generalization of habituation of capture can be observed with appropriate training (Vatterott et al., 2018).

Characteristic #8: "*Presentation of another (usually strong) stimulus results in recovery of the habituated response (dishabituation)*".

This characteristic describes the phenomenon of dishabituation, namely the fact that during habituation to the stimulus X, the occurrence of a new stimulus Y usually produces a response recovery to X when this is reintroduced (Steiner & Barry, 2014). The phenomenon of dishabituation has been partially documented for the oculomotor capture (Bonetti & Turatto, 2019), and only very recently Turatto and De Tommaso (2023) have found results that might be compatible with the dishabituation of onset capture. It must be noted, however, that for the problem discussed previously in relation to RT averaging, in a typical attentional capture study it might be complicated to detect signs of dishabituation, especially if dishabituation is very short-lived, and might dissipate in a single distractor presentation (for a similar argument about the difficulty to measure dishabituation with ERPs see Öhman et al., 1972).

Characteristic #9: "*Upon repeated application of the dishabituary stimulus, the amount of dishabituation produced habituates (this might be called habituation of dishabituation)*".

This characteristic is an extension of the previous one, but it could be difficult to find evidence of this sort in relation to the attentional capture response for the methodological reasons outlined previously.

In addition to the nine characteristics illustrated above, it might be worth mentioning two other features of habituation. First, as any other learning-based phenomena relying on memory, habituation can be short lasting (known as *short-term* habituation) or long lasting (known as *long-term* habituation). Of course, the temporal boundary between short-term and long-term habituation is not clear cut (Davis, 1970): in classic habituation studies the response decrement observed after a few continuous repetitions of the same stimulus is considered a form of short-term habituation. By contrast, long-term habituation should emerge when a "sufficient" time interval, ranging from minutes to hours, and depending on the specific animal species tested, is interposed between the training and test session. As for humans, we have shown that habituation to onset distractors presents both short-term and long-term components, where habituation was considered short term across blocks of trials, where it was considered long term across days of training (Turatto, Bonetti, & Pascucci, 2018; Turatto & Pascucci, 2016).

A final characteristic that is not typically mentioned among those that define habituation is that this form of learning can be context specific (Dissegna et al., 2021). One possible reason why this feature is often omitted is that it relies on associative learning mechanisms that bound together the response attenuation with a specific context or environment where the habituating stimulus is experienced. By contrast, habituation, together with sensitization, is instead classically considered to represent a form of non-associative learning, with conditioning being the prototypical form of associative learning. However, there is robust evidence showing that in some cases the habituated response recovers, partially or completely, in a different context, whereas it remains attenuated in the same context in which learning took place. Accordingly, we have shown that the habituation of capture, namely the rejection of repetitive onset distractors, is specific for the context in which it takes place (Turatto, Bonetti, & Pascucci, 2018; Turatto et al., 2019). This issue will be specifically discussed below.

Models of habituation

Habituation is the term used to define the progressive response reduction to an iterative stimulation, a reduction that cannot be accounted for by sensory adaptation or motor fatigue (Harris, 1943; Thompson, 2009). Therefore, the term *habituation* cannot be used to explain the response decrement, as it only describes the response pattern. Instead, we need a mechanism that accounts for habituation, and with this regard three classic theoretical models were developed in the 1960s and 1970s, while more recent computational models have also been proposed (e.g., Ramaswami, 2014). The three models present some commonalities but also important differences (also see

Thompson, 2009), as they originate from different lines of research and theoretical frameworks.

The Grooves and Thompson model

Among the different models of habituation, the Groves and Thompson (1970) one is certainly the less "cognitive" than others, as it was originally concerned with habituation of the limb motor reflex. The model, also known as the *dual-process theory*, proposes that two independent but interacting neural systems exist, and their combined activities determine the final motor output. The *dual-process theory* was supported by electrophysiological recordings (Glanzman et al., 1972; Groves et al., 1969), showing two main types of interneurons reacting differently to the stimulus repetitions: the *Type-H* neurons (responsible for habituation) systematically decreased their response to the repeated stimulation; the *Type-S* neurons (responsible for sensitization) showed an initial response increment before decreasing their activity with repetitions. Habituation occurs because with repetitions there is a general decrement in synaptic transmission, which can be accounted for by synaptic depression mechanisms (Groves & Thompson, 1970; Thompson, 2009). The shorter the ISI the more the synaptic depression accumulates at each stimulus repetition, and conversely the more it dissipates the longer the ISI. This can explain one of the most important and robust characteristics of habituation, namely the fact that habituation, as we have seen, is stronger/faster the higher the frequency of stimulation. The same time-dependent mechanism can also account for the spontaneous recovery of the habituated response when the stimulus is omitted for a sufficient interval of time.

The Sokolov model

The habituation model devised by Sokolov was in fact a more general model regarding the mechanism governing the OR and its extinction with stimulus repetitions (Sokolov, 1960, 1963). Sokolov's model, also known as the *stimulus-model comparator theory*, is particularly relevant to the attention-research community, as it deals with the exogenous orienting of attention and its habituation.

The OR consists of a constellation of skeletal and visceral muscular responses, electrocortical activities, and physiological reactions, all accompanying the orienting of attention toward the stimulus of interest (Barry, 2009). Although Sokolov assumed that both voluntary and involuntary attention components were parts of the OR, his theory is mainly known for, and as a matter of fact was more focused on, the habituation of the exogenous orienting triggered by a novel or deviant event. Hence, here I will also concentrate the discussion on the reflexive component only, which corresponds to the stimulus-driven attentional capture response.

The basic idea behind Sokolov's theory is that when a stimulus is registered by the central nervous system, a corresponding neural model is formed, which is continuously updated by new inputs and basically represents the statistics of past stimulus occurrences. Each input stimulus is compared with the existing model, and if a match is found the OR is inhibited, with inhibition accumulating at each input repetition, leading to habituation. By contrast, a new input stimulus that does not match the established model will trigger an OR.

The key point is that the current sensory input would not be compared with a model consisting of a passive memory of the past stimulation, but with an "expectation" about the upcoming event based on the statistics of the past events (also see, Öhman, 1979). In other words, a statistical learning process based on the past events is used to make predictions about the next expected event, an idea that Sokolov made explicit in various passages of his works. Here a few examples: "*The nervous system thus elaborates a forecast of future stimuli as a result of repeated stimulation and compares these forecasts with the stimuli actually in operation*." (Sokolov, 1960); "*… the nervous model should not be conceived of simply as a passive stable engram, but as a mechanism which can extrapolate the patterning of future nervous impulses.*" (Sokolov, 1963); "*Prediction is made on a probabilistic basis, using, for example, past conditioning history",* or *"This process of expectation (or hypothesis generation) and testing has been related to the OR by Feigenberg (1969), who argued that the organism makes a probabilistic prognosis (prediction) of future environmental events."* (Sokolov, Spinks, et al., 2002).

Hence, according to Sokolov's model, habituation arises when there is a match between the *input* stimulus and the *expected* one, which is equivalent to say that habituation develops because the information content of input stimulus, or *entropy* in terms of the Information theory (Shannon, 1948), decreases at each repetition. Conversely, the OR emerges when the stimulus has information content because it is a surprising event, i.e., when there is a mismatch between the current input and the predicted one (Itti & Baldi, 2009). In other words, the OR takes place when there is a *prediction error*, a notion that after Sokolov has become central in different domains of psychology and cognitive neurosciences (Den Ouden et al., 2012), inspiring for example the notion of predictive coding (Rao & Ballard, 1999).

The Wagner model

The habituation model proposed by Wagner (Wagner, 1976, 1978, 1979) is in many respects similar to Sokolov's theory, although its "predictive" nature is less prominent, as Wagner was less concerned with the decreasing response to a sequential pattern of stimuli, and much more focused on the role of both associative and priming mechanisms in determining habituation. A peculiarity of Wagner's theory is that it specifically predicts that (long-term) habituation should be context specific, which is a claim that has found empirical confirmations from studies with different animal species (Dissegna et al., 2021).

The theory essentially postulates that the degree to which a stimulus is capable of eliciting a response, or to form associations with other stimuli, namely the efficacy with which the stimulus is processed in general, depends on how strongly it is already represented (primed) in short-term memory (STM) at the time of its occurrence (Kamin, 1968). In other words, the more a stimulus is primed in STM the weaker the response it generates when it is re-encountered, which leads to short-term habituation (Wagner, 1976). However, because the STM representation decays over time, the shorter the ISI the stronger the priming effect and therefore the resulting habituation, whereas the longer the ISI the weaker the priming effect and the resulting habituation.

The model predicts that long-term habituation should be context specific because a stimulus always appears in a given context, and during the iterative presentations the stimulus forms associations with the context in LTM. When the same context is encountered in the future, it automatically retrieves the stimulus representation in STM, thus making long-term habituation context specific. In other words, the context would work as a predictor of the stimulus occurrence, because it primes the stimulus representation in STM, and when stimuli are represented in STM they are in a sense "expected". This view is supported by different observations showing that habituation of capture by visual onset distractors is context specific (e.g., Turatto, Bonetti, & Pascucci, 2018; Turatto et al., 2019).

From the description of the three habituation models, it is evident that at least Sokolov and Wagner conceived habituation as being regulated by cognitive processes, which comprise memory, (statistical) learning, priming and prediction. This should definitely make habituation a phenomenon of interest for cognitivists in general, and specifically for those studying the control of attention (Cowan, 1988; Dukewich, 2009).

Distractor rate, prediction and habituation of capture

As discussed previously, one of the most important and robust characteristics of habituation is its dependence on the temporal frequency of stimulation. What has been systematically documented across different animal species, from worms to rats and humans, is that short-term habituation, namely habituation within the same training session, is stronger and/or faster the higher the frequency of stimulation (Askew, 1970; Broster & Rankin, 1994; Davis, 1970; Geer, 1966; Thompson & Spencer, 1966).

An interesting question is whether the frequency of stimulation has a similar effect on the habituation of capture. However, answering this question is not straightforward because in typical attentional capture paradigms, both with feature and onset singletons, the distractor rate or probability is varied rather than the distractor temporal frequency (e.g., Müller et al., 2009; Turatto & Pascucci, 2016). There is a direct relationship between the distractor rate and its temporal frequency: a higher distractor rate results in shorter intervals between two distractor-present trials, which leads to a higher distractor temporal frequency, given a fixed number of trials. However, we have recently shown that the habituation of capture triggered by an irrelevant onset is controlled by the distractor rate, rather than by its temporal frequency of appearance (Turatto & Valsecchi, 2023). We found that habituation was stronger for high-rate distractors than for low-rate distractors, even when the two conditions were matched in terms of distractor temporal frequency. This means that the key factor controlling habituation of capture was the distractor rate, which we assume was used by the human cognitive system to make predictions or expectations about the distractor occurrence, for example at a given location. Since a high-rate distractor is more expected, and therefore less surprising than a low-rate distractor, the capture response was more strongly attenuated for higher than lower distractor rates.

In addition, in the same study we found a stronger habituation of capture for the high-rate than for the low-rate distractors when the absolute number of distractors presented in the two conditions was identical. This results further strengthened the hypothesis that the distractor rate determined the distractor expectation, which modulated the amount of habituation (Sokolov, Spinks, et al., 2002). In contrast, these results appear to contradict the model proposed by Groves and Thompson (1970), which suggests that habituation should be proportional only to the number of stimulations delivered to the nervous system.

The central role of expectation in controlling the capture response evoked by a distractor has been recently confirmed by a study that I conducted together with Matteo De Tommaso. We showed that the same onset distractor was subject to habituation across three consecutive blocks of trials, in which the distractor invariably appeared at a fixed time interval from the display onset. However, on a minority of trials of the fourth block the distractor unexpectedly appeared slightly delayed (about 1 second later), and it fully captured attention again (Turatto & De Tommaso, 2022). In our view, the occurrence of the delayed onset violated the expectation-based model of the same onset distractor built during the previous training phase, and therefore generated a prediction error that triggered a new attentional capture.

Habituation of capture and the role of contextual information

Habituation, together with sensitization, is generally defined as a prototypical example of non-associative learning. The reason is that, unlike conditioning where learning regards the relation between two stimuli, CS and US, in habituation the organism only appears to learn something about the US. However, as postulated by the Wagner theory (Wagner, 1976), habituation, at least in its long-term component, is hypothesized to be context specific. This is because the habituating stimulus obviously does not occur in the emptiness, but instead appears always in a given context, which can influence different key brain functions (Maren et al., 2013). Of course, defining what constitutes a context can be challenging, but in general by context it is meant the set of "circumstances" in which an event takes place. Here, I am restricting the definition of context to the spatial arrangement of the stimuli among which the distractor appears. These, as we will see, can be formed by the background over which the distractor appears, or by the stimuli configuration forming the search display. Yet, another possibility is that the context might be defined also by the observer's task during distractor presentation.

Hence, as predicted by Wagner's model, during the habituation training associations would be formed in memory between the stimulus and its context, such that contextual information can be used to anticipate or generate expectations about the stimulus appearance, thus favoring the filtering of the unwanted stimulation. However, the stimulus expectations should remain restricted to the context in which habituation has originally taken place, and in agreement with this theoretical view, we have shown that habituation to onset capture is context specific, or to put it more broadly that distractor filtering is context specific (Turatto, Bonetti, & Pascucci, 2018; Turatto et al., 2019). This conclusion was supported by different findings. First, we found that the "extinction" of habituation, and therefore the recovery of capture, occurred when the distractor was first omitted and then re-introduced in the specific context in which habituation originated; by contrast, the removal of the distractor in a different context did not disrupt the retention of habituation (Turatto, Bonetti, & Pascucci, 2018). Second, we also documented that when the context (defined by the background image) in which the distractor appeared changed from the training to the test phase, the distractor interference recovered completely in the new context (Turatto et al., 2019). The fact that habituation to onsets is context specific was confirmed also by experiments showing the *latent inhibition* phenomenon in onset capture. In other words, if participants are pre-exposed to a given context without the distractor, then habituation to onsets in the same context is weakened as compared to when the same onsets are seen in a different context (De Tommaso, Chiandetti & Turatto, 2023). Yet, studies with feature-singleton distractors have failed to find analogous findings, suggesting that distractor filtering is not context specific (Britton & Anderson, 2020; de Waard et al., 2021). However, evidence exists that have confirmed our original findings, showing that also feature-singleton distractors rejection is specific for the context or configuration in which distractors have been experienced (e.g., Allon & Leber, 2019; Gao et al., 2022).

The data showing that habituation of onset capture is context specific provide further support to the idea that habituation is controlled by cognitive processes, which among other things involve the formation of associations between the distractor and the surrounding stimuli configuration. As I will discuss below, the context specificity of capture habituation is also strong evidence against the possibility that the observed response decrement can be explained by sensory adaptation.

Automaticity and intentionality of habituation

Different mechanisms for distractor filtering have been proposed, and one of the most debated issues is whether such mechanisms are under voluntary control or alternatively whether they are automatically triggered, for example, by the statistics of the distractor occurrence (Chelazzi et al., 2019; Geng, 2014; Geng et al., 2019; Liesefeld & Müller, 2019; Luck et al., 2021; van Moorselaar & Slagter, 2020; Wang & Theeuwes, 2018a). In the same vein, one may wonder whether habituation of capture results from an automatic or a voluntary-controlled mechanism for the filtering of the irrelevant sensory input. If one considers the Groves and Thompson (1970) model it is quite evident that the proposed habituation mechanism operates automatically at the neural-synaptic level on the basis of the mere stimulus repetition. Given their cognitive nature, the question of a putative involvement of voluntary processes in habituation might seem more pertinent for what concerns both the Sokolov (1963) and the Wagner (1976) models. However, although both models assign a key role to STM for the maintenance of the representation of irrelevant sensory input (Sokolov, 1969; Sokolov, Spinks, et al., 2002; Wagner, 1976), and for comparison or priming processes regarding the current and previous stimulations, none of the two models assumes that habituation requires a volitional act of ignoring the repetitive stimulation. On the contrary, Sokolov for example was quite explicit in claiming that "… *it would be this automatically generated prediction of sensory events rather than just a memory of past events that is continuously compared with the current sensory input if sensory events display some temporal regularities... It is remarkable that all these cognitive processes are of automatic nature*." (Sokolov, Spinks, et al., 2002, p. 276). The idea that habituation reflects a filtering process automatically or passively engaged to prevent an attentional processing of the irrelevant repetitive stimulation is also in line with the model proposed by Cowan (1988). According to this model, stimulus repetition leads by default to habituation, unless the repeated stimulus is voluntary attended. Furthermore, the automatic nature of habituation finds additional experimental support in the observation that the interference caused by visual distractors is largely attenuated when humans are simply passively exposed to the irrelevant stimuli before the task (Turatto, Bonetti, Pascucci, et al., 2018; Won & Geng, 2020). Because during the passive-viewing phase participants were not engaged in any discriminative task, there is no reason to assume that the filtering mechanism was deliberately implemented because at some level the cognitive system "realized" that the irrelevant salient events caused a misallocation of attention and interfered with target discrimination (but see Allenmark et al., 2022).

As we have seen, Sokolov's model of habituation relies on mechanisms that automatically generate expectations on the basis of the statistics of past events, and that inhibit the OR toward the sensory input when this matches the resulting predictions. In line with the notion that distractor filtering is an automatic process, a study by Wang and Theeuwes (2018a) has shown that distractor suppression is not under voluntary control, being instead determined by the mere statistics of the distractor occurrence. The automatic or involuntary nature of experience-based forms of distractor filtering appears also in agreement with the fact that feature-singleton distractor rejection based on statistical regularities does not seem to require significant STM (or WM) resources (Gao & Theeuwes, 2020). In contrast, the idea that habituation of visual attention capture is an automatic process that apparently does not require the involvement of limited executive control resources, appears to be challenged by the results of studies on the *irrelevant-sound effect*. These studies have documented that the presentation of auditory distractors can disrupt visual discrimination and memory tasks by diverting attention from the visual to the auditory modality, thereby degrading visual performance (Turatto et al., 2002).

This cross-modal capture effect is also subject to habituation (Bell et al., 2012; Röer et al., 2014; Sörqvist et al., 2012), and interestingly WM capacity appears to modulate the habituation rate, thus suggesting that habituation of capture, at least in the auditory modality, is not a resource-free process (Sörqvist, 2010; Sörqvist et al., 2012; Sörqvist & Rönnberg, 2014). At present it seems difficult to reconcile these results with those emerged from the visual modality (e.g., Gao & Theeuwes, 2020), and further research is needed to determine to what extent habituation (or attenuation) of visual attention capture demands cognitive resources. This is especially relevant given recent findings that have demonstrated a more complex relation between attention and working memory (Ravizza & Conn, 2022).

Overall, based on the current evidence, habituation mechanisms are automatically engaged by the mere repetition of an irrelevant sensory input in the case of visual onset distractors (e.g., Turatto, Bonetti, Pascucci, et al., 2018; Won & Geng, 2020). However, it's important to note that "automatic" here simply means that habituation of capture does not require that the organism is voluntarily trying to ignore the distractor (also see Won, 2021). Nonetheless, it remains to be established to what extent forming and maintaining a template or model of the distractor requires the involvement of mechanisms of limited capacity (such as the WM), and how many concurrent models can be used or maintained when different irrelevant sensory inputs are encountered.

A further and somehow related issue is whether habituation of capture emerges from a reactive or a proactive mechanism, which is also a question highly debated with respect to the nature of the distractor rejection mechanisms in general (Chelazzi et al., 2019; Geng et al., 2019). None of the models that I have presented seems to work in a proactive fashion: the Groves and Thompson model depends only on the stimulation of the H-type or S-type neurons, and habituation in the Sokolov model results from the fact that the orienting response triggered by the distractor is suppressed when the latter matches the expected input (a similar mechanism operates also in the Wagner model). Therefore, the presence of a sensory input is mandatory for engaging the habituation processes, which defines the Sokolov model as a reactive filtering mechanism.

Attenuation of distractor interference: habituation, sensory adaptation or motor fatigue?

Although by definition a response attenuation due to a recurring stimulation might be in principle an instance of habituation, yet the reduced capture observed for a distractor that is repeatedly presented may have in fact alternative explanations. Two possibilities must be considered: sensory adaptation, and motor fatigue. These alterative accounts must be excluded before interpreting the response decrement as a case of habituation.

Can a sort of motor fatigue explain the habituation of capture in humans? One possibility is that habituation of capture might result from a weakening in the reflexive saccadic activity elicited by a distractor due to oculomotor fatigue, but this scenario seems very unlikely for several reasons. First, in many attentional capture studies participants are asked to maintain the eyes on the central fixation point, which excludes any fatigue in the oculomotor system. Second, when fixation is not required, or is not strictly controlled, the distractor occurrence might lengthen RTs because it triggers a reflexive saccade toward the corresponding location (Theeuwes et al., 1998), and the resulting oculomotor activity could be subject to fatigue. However, since the distractor is presented only on a proportion of the total trials, and each trial lasts a few seconds, distractor-triggered saccades have a much lower rate than normal saccades in free viewing (3-4 per second). In this condition no fatigue in the oculomotor system is observed, unless participants are engaged in a prolonged strenuous physical activity (Connell et al., 2017), which is not prototypical of an attentional capture experiment. Third, no sign of saccadic fatigue has been found during habituation of the oculomotor capture by visual onsets, as the saccadic latency toward the target was not affected by the saccadic habituation to the distractor (Bonetti & Turatto, 2019).

If it can be safely concluded that (oculomotor) fatigue cannot account for the habituation of capture, things are potentially more complex when sensory adaptation is considered, which can also be explained in terms of neurons fatigue (Carandini, 2000). Adaptation consists in changes in neurons' response properties induced by the recent stimulation, and visual adaptation typically produces perceptual consequences called *aftereffects*, which can be used to distinguish at what stage of neural coding adaptation is taking place (Webster, 2012). For example, in the visual system light-intensity adaptation can take place as early as in the retina, giving rise to negative afterimages. By contrast, adaptation to more complex stimulus attributes like orientation or motion direction of a visual pattern, generates the *tilt-after effect* and the *motion-after effect* respectively, which require the contribution of cortical neurons. Adaptation and the relative perceptual after-effects are hypothesized to occur because the prolonged exposure to a given visual pattern, called adapter, 'fatigues' those neurons (i.e., reduces their responsivity) that most strongly respond to the adapter features, like for example its orientation. Hence, the contribution of these less-responding neurons to the coding of a test pattern, with a different orientation from the adapter, is weaker than it would normally be. As a result, the perception of the test pattern orientation is shifted away from that of the adapting pattern (Carandini, 2000; Kohn, 2007).

Because both adaptation and habituation represent a response decrement after prolonged exposure to a given stimulation, it is critical to understand whether the two terms refer to distinct processes or instead reflect the same mechanism. Habituation studies have historically proposed that habituation can be distinguished from sensory adaptation because of the phenomenon of dishabituation, or on the basis of the effect of stimulation frequency on the time of response recovery (Rankin et al., 2009; Thompson, 2009). As a matter of fact, however, these solutions seem more adequate to exclude a role of sensory or receptor adaptation, but they appear less convincing to rule out adaptation that might take place at higher order cortical areas, and regarding more abstract or cognitive stimulus properties. For example, aftereffects have been shown for the perception of human face gender (Webster & MacLeod, 2011), or for facial expression (Hsu & Young, 2004), which are properties that are much less likely to be extracted at early sensory stages of visual analysis (Webster, 2012). When effects of a prolonged exposure are seen for high-level stimulus properties it might become difficult to distinguish between adaptation and habituation, and to the best of my knowledge no study has so far defined clear boundary conditions, if any, between the two phenomena. However, visual distractors used in typical attentional capture studies are stimuli defined by very simple visual features, such as for example color or luminance, as in the case of color-singleton or onset distractors (Jonides & Yantis, 1988; Theeuwes, 1992). In this case, it could be easier to rule out the contribution of sensory adaptation occurring at early stages of visual analysis to explain the capture attenuation observed with practice (Ferrante et al., 2018; Goschy et al., 2014; Müller et al., 2009; Pascucci & Turatto, 2015; Turatto & Pascucci, 2016; Wang & Theeuwes, 2018b). The adaptation account would indeed assume that through repeated exposures of the same distractor, neurons coding its features become fatigued. Hence, the distractor neural representation would be gradually weakened, which in turn would trigger a progressively weaker capture of attention.

Some indications suggest instead that the observed capture attenuation is not an instance of adaptation. First, typically visual adaptation requires tens of seconds of continuous exposure to the same pattern of visual stimulation to produce appreciable perceptual aftereffects (Webster, 2012). By contrast, in attentional-capture studies events are such that in each trial the distractor is presented for a few hundreds of milliseconds, or in some cases for a few seconds, followed by an equivalent (or longer) period when the distractor is not displayed on the screen, which do not seem to be the ideal conditions to elicit sensory adaptation. Second, and related to the previous point, I am not aware of any study in which participants have reported perceptual changes in the distractor luminance or color. However, I must admit that this is not strong evidence against a possible adaptation to the distractor, as I suspect that participants have never been explicitly inquired about possible perceived changes in the distractor appearance during the experiment.

In my view, however, the most convincing and conclusive evidence against the adaptation hypothesis comes from the results of a study that we have conducted a few years ago on the habituation to onsets capture (Turatto, Bonetti, & Pascucci, 2018). On day 1 participants were exposed for five blocks of trials to a visual onset distractor while performing a target discrimination task. The display consisted of four grey circles serving as placeholders. The target appeared in one of the circles, which was clearly cued, whereas on 50% of the trials one of the remaining placeholders was briefly illuminated before the target, thus serving as distractor. As in previous studies, we found a reliable capture attenuation with training, with distractor interference decreasing across blocks. Then, on day 2 participants were divided into two groups: the "extinction" group performed the same task for five blocks without the distractor, whereas the "control" group was not involved in any experimental activity and was not summoned to the lab. On day 3, both groups were tested in a single block of trials with the distractor (as in day 1), but before the test phase the “extinction” group performed another four blocks of trials without the distractor. The results showed that capture recovered only in the “extinction” group but not in the “control” group, an outcome that is consistent with the fact that habituation can be context specific (Dissegna et al., 2021). As predicted by Wagner’s theory, on day 1 the context, defined by the four-placeholder configuration, acted as a predictor of distractor occurrence for both groups, thus promoting habituation. On the subsequent days, however, the context became a predictor of the distractor absence for the “extinction” group. By contrast, the context remained a valid distractor predictor for the “control” group, which never performed the task without the distractor, thus avoiding the extinction of habituation. This group showed instead a full retention of habituation to onsets from the training phase of day 1 to the test phase of day 3. It seems difficult to explain this overall pattern of results in terms of visual adaptation.

Indeed, if adaptation depended on sensory fatigue in the neurons coding the distractor, it should have been equally dissipated or maintained in both groups, as the distractor was omitted in both groups from the end of training in day 1, to the test phase in day 3. In fact, it could be argued that on each trial of the training phase in day 2 (five blocks) and day 3 (four blocks), participants in the "extinction" group continued to be exposed to the onset of the four placeholders occupying the same retinal coordinates of the distractor seen in day 1. Although the placeholders were dimmer than the distractor, they were still luminance stimuli that impinged on the same neurons that were previously (putatively) fatigued by the distractor in day 1. Hence, because adaptation is stronger the longer the period or occasions of stimulation, one could have expected adaptation to be maintained more in the "extinction" group than in the "control" group, with the "extinction" group showing persistent capture attenuation (i.e., habituation) across blocks. By contrast, the reverse pattern was observed, as capture recovered only in “extinction” group, but remained attenuated in the “control” group. This is the opposite of what the adaptation account would predict, but is a result instead compatible with the habituation account in general, and more specifically with the fact that habituation can be promoted by contextual information, where the context acts as a predictor of distractor occurrence.

In sum, although the question of whether adaptation can provide an alternative account to habituation for the reduced responsiveness observed with a repeated or prolonged stimulation has been debated before (Dannemiller & Banks, 1983; Rankin et al., 2009; Slater et al., 1984), for the reasons outlined above visual adaptation seems unlikely to explain the attenuation of the capture response, leaving habituation as the most reasonable explanation.

Conclusions

For several decades after its discovery Pavlovian conditioning remained in general misconceived among psychologists, who did not recognize its intrinsic cognitive nature (Rescorla, 1988). More or less the same fate seems to affect the notion of habituation which, among cognitivists and especially those studying attention, is often erroneously interpreted as a peripheral, and therefore marginal phenomenon arising from a progressive reduced processing of the stimulus at the sensory level. By contrast, as I have illustrated, habituation of the exogenous orienting of attention, specifically when triggered by an irrelevant visual onset, results from sophisticated cognitive mechanisms (Cowan, 1988; Sokolov, Nezlina, et al., 2002). Ultimately, such mechanisms make predictions about future events on the basis of the previous series of stimulations, and evaluate the information content (i.e., entropy) or "surprise" conveyed by the incoming sensory input when compared with the expected one. In other words, while unexpected or surprising events capture attention (Itti & Baldi, 2009), the more an event is repeatedly encountered the more it becomes expected, and consequently the more the corresponding capture is subject to habituation (Turatto & De Tommaso, 2022; Turatto & Valsecchi, 2023). This view of habituation echoes the idea that the brain is constantly trying to predict the sensory input (Clark, 2013), and the discrepancy between the actual sensory data and the internal model of the world is called prediction error. In this framework, exemplified by the predictive coding account of perception (Rao & Ballard, 1999), learning corresponds to the process of minimizing the prediction error, or in other terms, in reducing the surprise associated with a given input (Itti & Baldi, 2009), which is used to update the perceptual model. Bruce Bridgeman has highlighted Sokolov's pioneering work on using the concept of prediction to interpret brain functions (Bridgeman, 2013). Indeed, Sokolov showed that the brain responds not only to sensory input, but crucially also to the difference between the actual input and what is expected. As previously argued, when sensory input is expected or predicted, the brain responds less to it. This phenomenon can be observed in the habituation of attentional capture, as well as in the habituation of the OR more broadly.

The literature on attention capture has recently seen an increase in studies demonstrating that humans can learn to ignore visual distractors based on their frequency of occurrence, either in general or at specific locations. One explanation for this phenomenon is statistical learning, which has been used to account for the reduction in capture at locations where feature-singleton distractors appear more frequently (e.g., Ferrante et al., 2018; Goschy et al., 2014; Sauter et al., 2018; Wang &

Theeuwes, 2018b). In addition, it has been proposed that the capture reduction observed with a repeated exposure to a salient visual onset distractor can be an instance of habituation of capture (e.g., De Tommaso & Turatto, 2019; Pascucci & Turatto, 2015; Turatto, Bonetti, & Pascucci, 2018; Turatto & Pascucci, 2016), and this also when the onset distractor appears with different rates at different locations (Turatto & Valsecchi, 2023; Valsecchi & Turatto, 2022). Capture reduction due to habituation mechanisms or to statistical learning of distractor probability have often been presented as distinct tools that the brain can use to filter the irrelevant stimulation (e.g., Chelazzi et al., 2019; Geng et al., 2019; Luck et al., 2021; van Moorselaar & Slagter, 2020). However, as discussed here and elsewhere (Turatto & Valsecchi, 2023), at present there is no clear evidence to consider habituation mechanisms and statistical learning as alternative explanations, at least in the case of visual onsets. This is because learning the statistics of the past sensory events is one of the key processes at the core of the habituation mechanism, like that, for example, devised by Sokolov. Thus, it may be argued that the choice of terminology used to describe capture reduction and its underlying mechanisms is merely a matter of preference among researchers. Some may opt for the term habituation, and relate the mechanisms to those used in other neuroscience research areas (Thompson, 2009), while others may prefer the term statistical learning, which has become popular in the field of attention more recently (e.g., Wang & Theeuwes, 2018b).

If we assume that the attenuation of capture triggered by onset distractors (for which the notion of habituation has been mainly invoked) and by feature-singleton distractors (for which the notion of statistical learning is more common) is controlled by similar mechanisms (which might not be the case, Valsecchi & Turatto, 2022), then the habituation account is, in my view, preferable. Indeed, while the mechanisms underlying the filtering of feature-singleton distractors may be different from those involved in habituation, the habituation account still offers a more detailed theoretical explanation of how the brain learns, in general, to ignore or discard irrelevant sensory input. For example, Sokolov's model not only assumes that statistical information about distractors is extracted from past sensory input, as the statistical learning account does, but also postulates that this information is used to make predictions about expected input. Furthermore, the Sokolov model proposes that the sensory input is compared with these predictions, and the degree of habituation of capture is larger with a smaller mismatch. Conversely, if a consistent mismatch results from the comparison process, namely if the event is "surprising", an orienting of attention toward the new/unexpected sensory input is triggered. This approach also has the advantage of explaining habituation by appealing to the notion of prediction error, which governs other key brain/cognitive functions such as perception and learning, and is connected to the related concept of information entropy and "Bayesian surprise" (Itti & Baldi, 2009; Shannon, 1948; Sokolov, Spinks, et al., 2002).

The use of statistics of past events to generate predictions or expectations about future events, and the use of the discrepancy between the two to regulate the degree of suppression are processes that are not (at least explicitly) postulated in the statistical learning account. In contrast, in the case of statistical learning, suppression seems to be engaged by a mechanism that "realizes" that attention is misallocated to the distractor instead of the target (for a similar view also see, Allenmark et al., 2022). With this regard, it is debated as to whether the resulting suppression is exerted in an active top-down (e.g., Gaspelin & Luck, 2018a, 2018b) rather than in a bottom-up fashion (e.g., Wang & Theeuwes, 2018a). There is evidence, however, that distractor rejection can take place also in passive viewing (Turatto, Bonetti, Pascucci, et al., 2018; Won & Geng, 2020), which suggests that the presence of a target, that by instructions needs to be selected, is not necessary to filter the repetitive irrelevant stimulus (also see Won, 2021; but see Allenmark et al., 2022 for a different view).

Finally, if one considers a habituation model like that proposed by Wanger (1976, 1978, 1979), this predicts that habituation of capture should be context specific, and crucially it also offers a mechanism explaining why this should be the case. In sum, it seems to me that at present the statistical learning view does not present a theoretical explanatory level comparable to that offered by the habituation account.

Of course, it remains possible that the attenuation of capture observed in statistical learning studies, which largely employed color-singleton distractors, might be due to mechanisms different from those engaged by onset-singleton distractors. In that case, it should be specified how statistical learning and habituation mechanisms differ and the distinct predictions that these two mechanisms make. Regarding the relationship between habituation and attention, I view habituation as a manifestation of an experience-based mechanism that controls the allocation of attention. This mechanism is adaptive and widespread across both vertebrates and invertebrates, as it prevents the unnecessary allocation of limited processing resources towards repetitive irrelevant stimuli (Cowan, 1988; Siddle, 1991; Stephenson & Siddle, 1983).

In conclusion, in agreement with Cowan (1988) and Dukewich (2009) I believe that cognitive psychologists, and particularly those working in the field of attentional capture, should pay greater attention to the notion of habituation, a phenomenon controlled, at least in humans, by high-order cognitive processes, which affects a multitude of overt behavioral responses, but also a mental one like the covert capture of attention when an irrelevant salient sensory input like an abrupt onset event is repeatedly encountered.

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