Trends in Cognitive Sciences

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Opinion

The importance of an exaggerated attention bottleneck for understanding psychopathy

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The psychopath has long captured the imagination. A name such as Ted Bundy evokes a morbid curiosity. The crimes committed by Bundy are so cruel that it is hard to imagine how someone could do such things. In this review we discuss evidence that exaggeration in an attention bottleneck is one mechanism that makes it possible for psychopathic individuals to be adept at focusing on a single stimulus feature or goal but struggle to process multiple streams of information simultaneously. This exaggeration may partly explain the behavioral, affective, and social deficits that are apparent among psychopathic individuals. Further research on this attentional mechanism may promote a science that adequately captures the complexity of psychopathic behavior and offers new avenues for intervention.

Highlights

Psychopathic individuals show an uncanny ability to selfishly pursue their goals.

An exaggerated attention bottleneck is one potential mechanism that appears to underlie the self-centered, callous, and antisocial behavior of psychopathic individuals.

Abnormal attention influences the presence of canonical dysfunctions in regulated behavior, affect, and other-regarding processing in psychopathic individuals.

The specification of an exaggerated attention bottleneck in psychopathic individuals highlights avenues for future work on the development, management, and treatment of psychopathy.

Attention anomalies in psychopathy

Attention is fundamental for navigating our day-to-day physical and social environments. It influences the extent to which different sensory inputs are perceived, selected for action and learning, and stored in memory, and also affects how abstract information is represented [1–4]. Given the importance of attention in processing information and functioning, it makes sense that anomalies in attention characterize a variety of psychiatric disorders from attention-deficit hyperactivity disorder to depression to schizophrenia [5–7]. One particularly fascinating disorder associated with specific disturbances in attention is psychopathy.

Psychopathy is defined by antisocial behavior paired with callousness, low empathy, and low interpersonal emotions [8]. Psychopathic individuals, compared to non-psychopathic individuals, commit 2–3-fold more violent and nonviolent crimes and recidivate at a much higher rate. Consequently, they are responsible for a disproportionate share of the estimated $2.34 trillion in annual costs associated with crime in the United States [9].

Research suggests that the damaging behavior of psychopathic individuals is due, in part, to their uncanny ability to focus myopically on their selected goal [10–16]. Over the years several proposals and empirical studies have documented anomalies in attention among psychopathic individuals. However, previous attention models of psychopathy have been critiqued because the description of attention and related anomalies did not stem clearly from basic cognitive science [17]. Therefore, there was often a disconnect between clear evidence that attention operates differently among psychopathic individuals and the component of attention that appeared to be disrupted. Recently, research rooted in cognitive neuroscientific models of attention has identified one specific attentional impairment in psychopathic individuals – an exaggerated attention bottleneck.

Is an attention bottleneck anomalous in psychopathy?

Some components of attention function to select important aspects of the environment for further processing while filtering out less salient aspects of the environment. This filtering serves to make

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the amount of information manageable. However, there is often an associated cost: an attentional bottleneck can block encoding of information, disrupt decision-making for specific events, and bias response selection toward relevant information. The presence of this type of attentional bottleneck has been studied extensively under dual-task conditions.

Evidence supporting an attention bottleneck in neurotypical individuals

Research in neurotypical individuals has shown that reaction times to a second target are slower when presented quickly following a first target (i.e., 0–500 ms apart), but not when sufficient time is given between the first and second targets (e.g., 1100 ms between stimulus onsets) [18–24]. In addition, in other dual-task paradigms such as the attentional blink task, participants have a reduced ability to report the identity of the second target if it is presented between ~100 ms and 600 ms after onset of the first target and following a stream of distracters in a rapid serial visual presentation [25]. Processing limits in neurotypical individuals on dual tasks also have been shown to influence word production [26], the perception of time [27], and face recognition [28]. The performance decrements seen when tracking two or more tasks generally have been interpreted in terms of a bottleneck that restricts simultaneous processing, such that information is serially filtered in until it can clear the bottleneck, and goal-relevant information and/or salient features are prioritized through attentional processes [20,21].

Brain-based representations of this bottleneck appear to shift the latency and peak of neural processing under conditions of multi-tasking/component processing. Analysis of electroencephalography (EEG) data revealed that a significant delay of the P3 component (an indicator of stimulus evaluation) was evoked by a second target [24]. In addition, analysis of fMRI data has indicated heightened activation in prefrontal regions during multicomponent processing [20,21,24,29,30]. The lateral prefrontal cortex (lPFC), including the inferior frontal gyrus, has emerged as a purported neural substrate of this bottleneck, and demonstrated activation by tasks that place demands on multiple modalities, sensitivity to response selection demands, and serial queuing of response selection. Furthermore, the application of transcranial direct current stimulation to the lPFC during a dual task diminished the cognitive and behavioral costs of dual-task demands, thereby substantiating the role of the lPFC in multitasking [19]. In addition to the lPFC, the superior medial frontal cortex has been shown to support the processing of serial queuing. These regions are core nodes in neural networks related to attention and support the coding of task-relevant information (e.g., location, object, and category information) [31], the flexible reallocation of attention on the basis of changing task demands [32], and guides sensorimotor choices [22,33,34] (Figure 1).

Evidence supporting an exaggerated bottleneck in psychopathic individuals

The attention bottleneck model of psychopathy asserts that the effects of a bottleneck are amplified among psychopathic compared to non-psychopathic individuals, such that the processing of secondary streams of information (regardless of their potential value or relevance) is increasingly delayed or is completely inhibited [35,36]. An excessively active (i.e., exaggerated) attention bottleneck may allow psychopathic individuals to be more effective at filtering out distractions and focusing on personal goals, but may also leave them vulnerable to over-prioritizing goal-relevant or particularly salient information at the expense of other important context-relevant information.

Across tasks commonly used in neurotypical individuals to capture a bottleneck, individuals with psychopathy display anomalies consistent with an exaggeration in bottleneck functioning. Individuals with higher psychopathy scores showed greater slowing of behavioral responses and a longer-lasting period of bottleneck-related interference in a classic dual-task paradigm [36]. The exaggerated bottleneck-related interference also mediated the relationship between

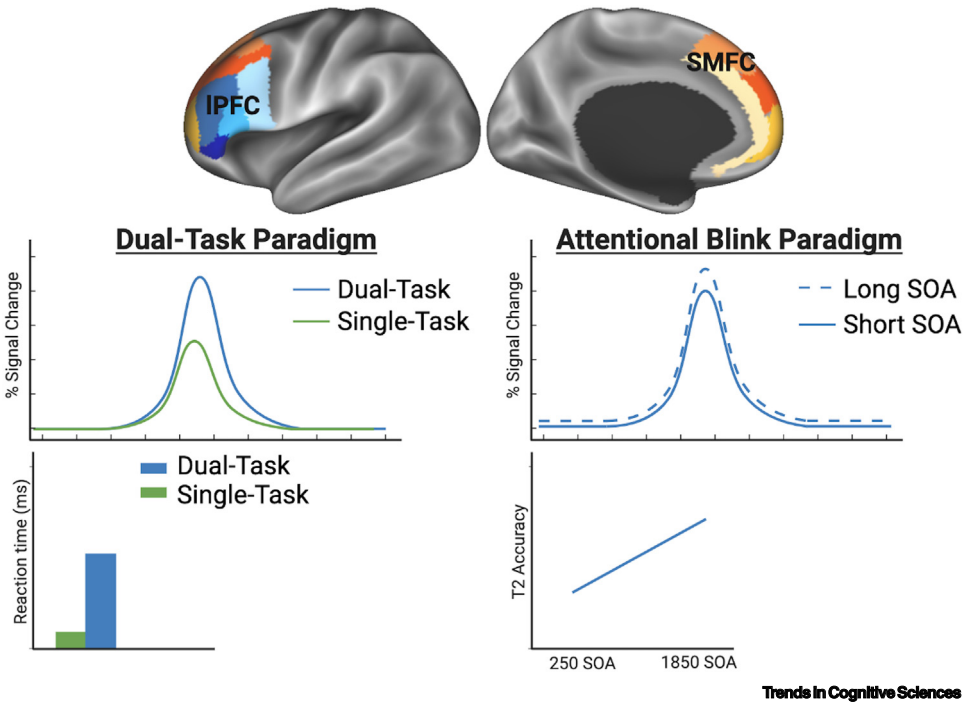

Figure 1. Basic science of an attention bottleneck. Research in neurotypical individuals has shown that lateral prefrontal cortex (lPFC, cool colors) and superior medial frontal cortex (SMFC, warm colors) are important supports for bottleneck functions. The lower portion of this figure displays the heightened neural signal and disrupted behavioral response during dual-task and attentional blink paradigms. Abbreviations: SOA, stimulus onset asynchrony; T2, second target.

psychopathy and real-world risky and impulsive behavior. In a study using the attentional blink task, individuals with psychopathy showed an attenuated blink, indicating that individuals with psychopathy screened out goal-irrelevant distractors more effectively than controls [37]. Finally, another behavioral study testing serial and simultaneous processing demonstrated that, compared to non-psychopathic individuals, psychopathic individuals display lower accuracy and longer response times when trying to process multicomponent perceptual information concurrently [38].

In addition to these basic dual-task paradigms, several studies in psychopathy have examined multi-task/component processing in the context of learning. Generally, psychopathic individuals displayed deficits in learning about reward and/or punishment, processing unexpected negative outcomes, and reversal learning [39–43]. However, in tasks that required participants to learn and track multiple sets or types of contingencies [39,43,44], the psychopathy-related deficits have been most apparent.

For example, psychopathic individuals showed a learning deficit when a passive-avoidance task included both reward for correct responses and punishment for incorrect responses, but not when only reward or punishment was involved [45,46]. Such findings indicate that a deficiency in passive avoidance learning becomes visible when multiple sources of information must be prioritized to adapt behavior in an optimal fashion. From this perspective, the presence of an exaggerated attention bottleneck would lead to insufficient distribution of attentional resources across both reward- and punishment-related information, leading to less efficient processing of different stimulus–outcome contingencies, which ultimately could impede how behavior is

adapted based on the contingencies. The impact of the bottleneck, however, is undetectable when only one type of contingency needs to be monitored because no other sets of contingencies are competing for the focus of attention.

A similar case can be made for studies focusing on reversal learning [39,40] or that used more than two contingencies to examine reinforcement learning in psychopathy [43]. In one study, participants performed a task in which they first were required to learn the probabilistic association between two predictive cues and either a Go or a NoGo stimulus using positive and negative feedback. Then participants were presented with a reversal of contingencies (i.e., the predictive cue for the Go cue now predicted the NoGo stimulus, and vice versa) [39]. In one version of this task, participants were not explicitly required to monitor the cues in addition to the Go/NoGo stimuli. In a second version of this task, participants were instructed to learn and track the predictive value of the cue as well as the Go/NoGo stimuli. Individuals with psychopathy and controls were equally capable of acquiring the contingencies and changing their behavior after reversal had occurred when they were not asked to actively monitor the cues. At face value, this effect seems to contradict the passive-avoidance findings where psychopathic individuals struggled to track both reward and punishment information. However, during the passive-avoidance tasks both reward and punishment competed equally for processing resources. By contrast, in this reversal-learning context there was little active competition between reward and punishment because the amount of negative feedback was negligible (<3% of trials), effectively giving the task a reward-only focus. Thus, psychopathic individuals showed normative learning when only a limited amount of serially presented information needed to be actively monitored. Conversely, psychopathic individuals showed slower learning following the reversal of contingencies when the instructions required them to pay attention to both the predictive cues and the Go/NoGo stimuli (e.g., a dual task). Thus, asking individuals to explicitly track multiple pieces of information could burden a bottleneck by prioritizing the predictive cues, the Go/NoGo stimuli, and their interdependencies. For psychopathic individuals, the exaggeration of their bottleneck made it such that they were less able to effectively track the reversals when a more substantial and complex presentation of information was provided.

Taken together, studies utilizing behavioral paradigms that typically engage multitasking capabilities and evoke bottleneck processing suggest that individuals with psychopathy display exaggerated bottleneck functioning. Additional support comes from evidence that neural processing in regions strongly implicated in bottleneck functioning (e.g., lPFC) reliably appear to be atypical in psychopathic individuals ([47–49] for meta-analyses). These findings across behavioral and brain studies emphasize that an exaggerated attention bottleneck in psychopathy may be an important mechanism to consider.

The dysregulated behavior seen in psychopathy during multitasking and learning seems to occur as a function of contextual demands. In real life, psychopathic individuals can appear to be controlled in their behavior in some circumstances but not in others. Evidence that anomalous bottleneck functioning is not always present (i.e., in relatively simple tasks) reflects the ecological reality of the various contexts that psychopathic individuals navigate. It is possible that psychopathic individuals initiate engagement in planned and reactive aggression, substance misuse, and impulsive decision-making in a more premeditated fashion, but then are unable to integrate contextual information, update information, and consider all contingencies (e.g., the absence or presence of safety signals, the potential for incarceration) associated with this action in real life partly because of the restrictions of information processing imposed by the exaggerated attention bottleneck.

Can an exaggerated bottleneck be reconciled with emotion-focused theories of psychopathy?

Individuals with psychopathy often are portrayed as innately fearless, callous, and unemotional. Psychopathic individuals do, in fact, display substantial deficits in emotion processing, including emotion recognition [50,51], affect-modulated startle [52], and fear/threat conditioning [53]. In addition, there is considerable evidence that the amygdala is one neural region disrupted in psychopathy [52,54,55]. Notably, however, evidence considered to offer the strongest support for emotion deficits in psychopathy comes from studies that use complex stimuli and/or that place demands on rapid processing (e.g., faces with blended emotions, novel complex pictures, subconscious stimuli, emotion as peripheral to another goal-focus) [56–58]. Therefore, it is difficult to disentangle the impact of limited emotional capabilities from abnormalities in handling cognitive load when tasks place demands on both aspects of information processing. Further, animal and human research on the amygdala highlights that this brain region performs functions beyond emotion processing [59,60] and that the amygdala is only minimally related to affective responses to threat [53,61]. Therefore, it seems reasonable to consider that, although difficulties with emotion processing are related to psychopathy, a straightforward explanation rooted only in blunted emotions and amygdala dysfunction does not adequately capture the various abnormalities apparent in psychopathy [54].

There is some evidence that a central bottleneck can impact early sensory analysis, object recognition, the integration of spatial and feature-based information, and ultimately the ability to extract meaning from stimuli [34,62–66]. In paradigms with dual-task demands, familiarity manipulations have demonstrated that unfamiliar faces require substantial attention resources and that presenting familiar faces reduces the attentional demands during face identification, thereby protecting against a bottleneck [28]. The use of rapid serial visual presentation indicated that encoding task-relevant information can compromise the encoding of subsequent information (task-relevant or -irrelevant) [62]. EEG studies, designed to parse early visual attention from visual representation, noted that encoding in such a way that supports conscious awareness was delayed significantly when participants needed to track and respond to multiple pieces of information [22]. Although the bottleneck has been tested most often in the context of dual-task paradigms, there is evidence that object perception, including faces, is modulated by attention and is partly dependent on serial processing [67–69]. Further, the lPFC is involved in face processing [70], is a crucial region where stimulus-driven and goal-directed attention converge [71], and may be a limiting factor in the amount of information that can be encoded [72]. Consequently, it has been suggested that bottleneck filtering that necessitates serial processing could impact processing and integration across various stimuli, including faces, perceptually complex images, and goal-relevant versus -irrelevant information.

Attention and affective processing in psychopathy

A core assumption of emotion theories in psychopathy is that psychopathic individuals fully process faces and other emotional cues. Faces are complex and salient stimuli that naturally draw and retain attention [73]; from an exaggerated attention bottleneck perspective, psychopathic individuals may struggle to efficiently encode, integrate, and extract all information about emotion from the face. Research shows that psychopathic individuals are capable of correctly identifying facial emotion when given sufficient time to process the information or only when a single emotion is displayed (e.g., 100% fear); however, psychopathic individuals appear to be disrupted in accurately identifying emotion when multiple emotions are blended or when the emotion cues are masked [74–77] (Box 1 for research in young people; see Outstanding questions for future research). It may be that psychopathic individuals are not fundamentally incapable of processing important affective cues, but that their exaggerated bottleneck limits their ability to do so effectively.

Box 1. Evidence of attention anomalies in young people with psychopathic traits

Recently, psychopathy has been conceptualized as a neurodevelopmental disorder rooted in so far unspecified disruptions in neurodevelopmental processes that may start at birth, if not before [100–103] (see Outstanding questions). Attention-based research on psychopathy largely focuses on adult populations and there have been no direct tests of the exaggerated attention bottleneck mechanism in youth. However, there are signs that attention anomalies such as those described in adults with psychopathy are apparent in young people with psychopathic traits [104–107]. Although much of the mechanistic work on young people with psychopathic traits focuses on emotion or other-related processing, there is evidence that differences in perceptual processing of visual cues impact on affective responding in young people with these traits [101,108–110]. For example, young people with traits of psychopathy were able to identify emotions when directed to focus on the eyes, but not when left on their own to process the entire face [109]. In addition, several emotion-focused studies in young people with psychopathic traits utilize subconscious manipulations or blended faces, making it difficult to disentangle the contributions of emotion and cognitive processing [111–114]. Moving beyond studies showing associations between psychopathic traits and purported cognitive-affective mechanisms and toward longitudinal work that captures multiple mechanisms is an exciting avenue for future work.

Other evidence for a core affective deficit in psychopathy comes from studies that assess potentiated startle responses using a picture-viewing paradigm. In contrast to non-psychopathic individuals, who display startle potentiation to noise probes while viewing unpleasant pictures and startle inhibition while viewing pleasant pictures, the startle potentiation to unpleasant pictures appears to be lacking in psychopathic participants [58,78]. Such results are often taken to suggest that psychopathic individuals engage their defensive system to a lesser extent in response to threats [53]. However, startle potentiation also reflects the engagement of sensory processes and attention allocation [79]. To the extent that a psychopathy-related exaggeration of an attention bottleneck fosters serial processing and constrains the simultaneous processing of picture elements, it would make processing less efficient and disrupt the fluent processing of complex pictures. As a result, the response to emotions may be attenuated because psychopathic individuals have not yet had sufficient time to integrate all the information (Figure 2). Thus, the attention bottleneck model of psychopathy would predict that, when presented with complex, affectively-laden, or novel pictures (enhancing cognitive demands associated with picture-viewing), psychopathic individuals will show a deficit in startle. However, when presented with simple or familiar pictures (reducing the cognitive demands associated with picture-viewing), psychopathic individuals will display normative affect-modulated startle. Consistent with these predictions, in two different studies, one in which picture simplicity versus complexity was manipulated and the other where picture familiarity versus novelty was manipulated, psychopathic individuals were able to display normative startle responses to simple or familiar pictures. But, replicating original picture-viewing research in psychopathy, were deficient when viewing complex or novel pictures [80,81].

Research on fear or threat conditioning in psychopathy also highlights how an exaggerated attention bottleneck can disrupt the flow of information processing in psychopathic individuals. Early work on classical conditioning in psychopathy documented that, although psychopathic individuals were able to discriminate between a conditioned and a neutral stimulus in terms of autonomic arousal and in rating the aversive salience of stimuli, they displayed reduced amygdala, orbitofrontal cortex, insula, and anterior cingulate cortex activation during acquisition [82]. The conditioning task often used involves learning that the picture of one of two faces presented on a screen is followed by an aversive stimulus (e.g., pressure, shock) ([82,83]; also [84]). Failure to learn such associations during conditioning among psychopathic individuals could, at least in part, be explained by the presence of an exaggerated attention bottleneck. Psychopathic individuals might take more time to fully process the faces as a result of the exaggerated bottleneck, at the expense of allocating sufficient resources to properly process the threatening shock that follows. Such an impairment would make it more challenging to accurately extract and accumulate all the information required to learn about how the face and the shock may be associated [85], ultimately resulting in diminished learning from threats.

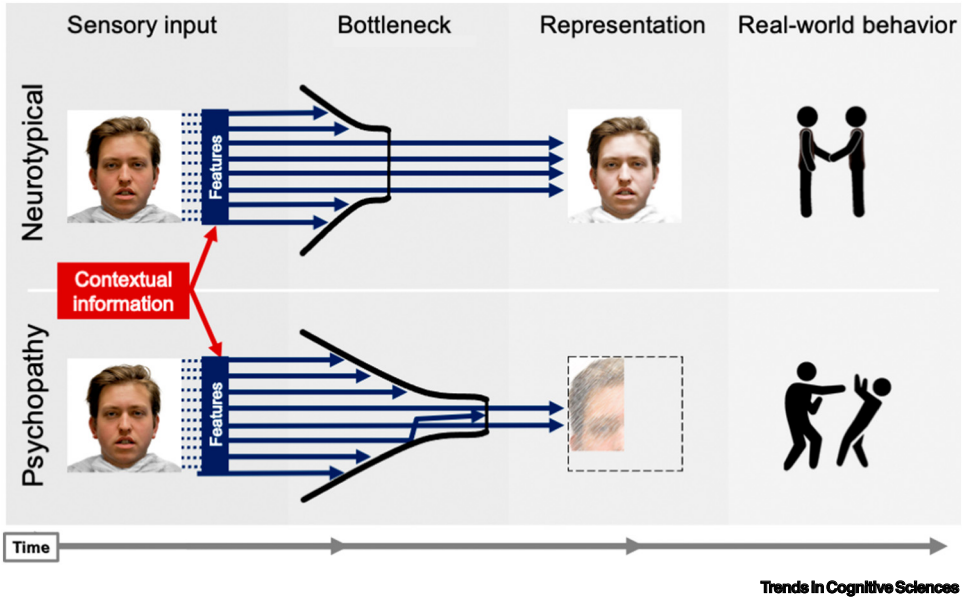

Figure 2. Schematic depiction of the attention bottleneck in neurotypical individuals and psychopathy. (Top panel) In neurotypical individuals, complex sensory information enters the attention bottleneck where a portion of the information is filtered out. Contextual information and instructions can affect prioritization of the features of the stimulus that pass through the bottleneck. Information that passes through the bottleneck is processed in parallel and used to quickly create a mental representation that closely resembles the stimulus. The mental representation serves as the input for subsequent stages of processing, guiding the choice for stimulus-appropriate behavioral responses. (Lower panel) An exaggerated bottleneck in psychopathy filters out a disproportionate amount of relevant information and necessitates serial processing of stimulus-related information. In the absence of sufficient time to process all the information, the mental representations of the stimulus may reflect only partial information, particularly at the timepoint when experimental studies probe emotion responses (dramatized in the figure). The degraded and fractioned representations ultimately have a negative impact on the choice of appropriate behavioral responses. Note: Sensory input images are from the RADIATE [99] stimulus set.

Similar to serial processing tasks that present goal-relevant and goal-irrelevant information in sequence, one study tested instructed threat conditioning where the goal-focus was on the threat information or on the non-threat information (i.e., a letter). The order of the information varied: in the early conditions, the primary goal-relevant information appeared first in the trial, whereas in the late conditions, the primary goal-relevant information appeared second in the trial after the goal-irrelevant information had been presented. These manipulations tested whether psychopathic individuals could respond to threat when it was the primary focus of attention, and whether disruptions in attention occurred as exaggerated serial processing (i.e., bottleneck) or at other stages. Psychopathic individuals showed deficient emotional reactivity in the condition where the focus was on the non-threat information that appeared first in the sequence, with the threat-related information following [35]. That is, psychopathic individuals prioritized the goal-relevant non-threat information, but were less able to process the subsequent contextual threat information. Moreover, lateral prefrontal cortex activation was increased only in this condition, and activation in the lateral prefrontal cortex mediated the association between psychopathy and amygdala dysfunction [11].

Most research on emotions and psychopathy has focused on basic emotions, such as fear and sadness. It is possible that the exaggerated attention bottleneck might impact more complex emotions in psychopathic individuals. A lack of regret is a cardinal trait of psychopathic individuals. Researchers using a counterfactual decision-making task found that psychopathic individuals reported similar levels of negative affect in response to regret-inducing counterfactual outcomes

as individuals without psychopathy [86]. This measure showed individuals their outcomes and asked them explicitly to rate their affect, effectively prioritizing the attentional focus on reward magnitude and affect-inducing information. However, despite exhibiting intact affective regret sensitivity, psychopathic individuals did not use prospective regret signals to guide choice behavior, perhaps reflecting difficultly in extracting meaning from the affect-related information. Further, individuals high on psychopathy and low on prospective regret had the greatest number of incarcerations, suggesting that a disconnect between present reactions and future considerations has real-world implications.

Together, these data show that psychopathic individuals can respond normatively to unpleasant images, fear, threat, and regret information. However, when this information is embedded in a complex display, involves salient faces followed by threats, is peripheral to another goal, or requires abstraction to future decisions, their exaggerated bottleneck may constrain the fluid processing and integration of important contextual information.

Attention and other-regarding processing in psychopathy

It is intuitive to think that the actions of those who continually violate the rights of others reflect an inability to feel or understand what others might be thinking or feeling. However, psychopathic individuals can connect interpersonally to arrange their relationships and social transactions in ways that will benefit them. Achieving this requires the capacity to understand the feelings of others (i.e., affective other-regarding processing) as well as their mental states (i.e., cognitive other-regarding processing). Research on other-regarding processing in psychopathy highlights how these individuals are both able to connect with others to achieve their goals while being unencumbered by the emotions of others [87].

Social interactions are cognitively and conceptually complex. Healthy interactions require an intact capacity to process and integrate multiple streams of information. An exaggerated attention bottleneck may restrict information processing in psychopathic individuals to such an extent that it leaves them with a fractionated view of the social world. As with the basic facial emotion work, it should then be possible to alleviate the processing load of psychopathic individuals in estimating the feelings and thoughts of others by manipulating how they engage with relevant social cues.

One study on the representation of the feelings of others used fMRI to examine neural responses to hand-pain under three different conditions [88]. In one condition, participants were asked to passively view a video clip of a hand being hurt (i.e., spontaneous other-regarding processing); in another condition participants were asked to imagine what the person in the clip might be experiencing (i.e., controlled other-regarding processing); finally, participants physically experienced the actual scenarios depicted in the clips. Psychopathic individuals did not exhibit similar neural responses to controls in their actual experience of pain when passively viewing the pain clips; however, psychopathic individuals showed similar neural responses to controls when instructed to imagine what the person was feeling or when physically experiencing the pain ([88]; also [89]).

In another study that measured understanding the thoughts of others, participants were presented with static scenes depicting an avatar in a room with varying numbers of dots on the walls [90]. The dots appeared in front of the avatar (i.e., the avatar had complete information), behind the avatar (i.e., the avatar had no information), or in both locations (i.e., the avatar had partial information); however, the participant always saw all the dots on every trial. In some trials the participants were asked to evaluate how many dots the avatar could see (other-trials), and in other trials the participants needed to evaluate how many dots they personally could see (self-trials).

The cue for which perspective to take was presented before the image of the avatar and dots in the room. The other-trials provided a measure of controlled processing: could the participant cognitively represent the avatar's perspective when instructed to do so? The self-trials provided a measure of spontaneous processing: did the avatar's perspective automatically influence the participant's perspective? Psychopathic individuals were able to engage in a controlled consideration of the thoughts of others but displayed significantly less interference on the spontaneous trials (i.e., their reaction time was not affected by the information available to the avatar). Moreover, reduced spontaneous interference in individuals high on psychopathy was related to involvement in assaultive behavior.

Overall, these findings suggest that psychopathic individuals can engage in affective and cognitive other-regarding processing, but do not do so without instruction. Across tasks it seems that instructions can initiate an inflexible focus that, in some situations, can negatively impact fluid processing (e.g., when the goal-related information is immediately apparent and contextual information is not sufficiently processed [35], or when there are multiple streams of information to integrate, see the explicit learning condition [39]). However in other situations, instructions can support effective goal-directed behavior, making psychopathic individuals appear typical in their behavior (e.g., when there is a singular focus with no or little competition for attentional resources or contextual information [90]; see the no explicit instruction condition [39]). Consistent with an exaggerated attention bottleneck model, psychopathic individuals can estimate the feelings and thoughts of others in a relatively typical manner when doing so is goal-conducive, and can ignore the feelings and thoughts of others when it is not goal-conducive. Thus, it may be difficult for psychopathic individuals to naturally estimate the affective and cognitive states of others in cognitively demanding and non-goal-relevant situations [15,91,92], something that non-psychopathic individuals do more automatically.

Concluding remarks

An exaggerated bottleneck appears to constrain the processing of information to such an extent that the fluid integration of information appears to be disrupted in psychopathy. We have highlighted how this view can (partly) explain various psychopathy-related findings across behavioral, affective, and social domains. Paradigms that use dual-task methods, manipulate processing load, and demand sequential processing emphasize that, at times, disruptions in the integration of information can result in a temporary advantage for psychopathic individuals, but in many instances and over time the difficulty in attending to and incorporating information fully undermines appropriate behavior. It seems clear that more is going on in the minds and brains of psychopathic individuals than simply blunted affect, distain for others, or cognitive impulsivity. An exaggerated attention bottleneck is one possible mechanism that warrants more research from the basic and clinical sciences.

As indicated in this review, psychopathic individuals are capable of more typical behavioral, affective, and other-regarding functioning when attentional demands are considered. This pattern of findings provides an opportunity to consider strategies for the management and treatment of these individuals that addresses constraints in their information processing [54] (see Outstanding questions). Preliminary evidence suggests that targeting attentional processing can bring about brain and behavioral change in psychopathic individuals [93,94]. Understanding the boundaries of information processing in psychopathic individuals will be essential in refining the conceptualization and handling of individuals with this costly psychiatric disorder.

The identification of an exaggerated attention bottleneck in psychopathy does not preclude other cognitive-affective dysfunctions. The lPFC and other bottleneck-related regions are far from being

Outstanding questions

How does aberrant functioning of the exaggerated attention bottleneck influence subsequent stages of processing (e.g., memory)?

How is the trade-off between externally oriented and internally initiated attentional resources affected in psychopathy? To what degree does a combination of attention abnormalities restrict the amount and complexity of information processing such that psychopathic individuals are better able to efficiently home in on relevant information?

How do the abnormalities in nearly all major neural networks interact with specific regional abnormalities related to the bottleneck?

How do multiple cognitive-affective dysfunctions in psychopathy interact?

How do attention aberrations develop in psychopathy? Is it possible that the thalamic reticular nucleus (TRN), a gatekeeper that filters incoming information in an early stage, might show atypical functional and/or structural maturation in psychopathy, ultimately contributing to the impairments associated with an exaggerated attention bottleneck?

Does an exaggerated attention bottleneck lead to the psychopathic phenotype, or is an exaggerated attention bottleneck merely associated with psychopathy?

Could consideration of an exaggerated attention bottleneck lead to the development of novel and more effective treatments for psychopathic individuals?

To what extent do attention abnormalities in psychopathy impact on how psychopathic individuals are handled in legal settings? Does the presence of an exaggerated bottleneck unambiguously qualify these individuals for insanity defenses as evidence of a 'mental disease or defect'? Does it represent compelling mitigating evidence that should be invariably accounted for in sentencing?

the only anomalous regions in psychopathic individuals. Whole-brain analyses indicate that many of the major neural networks are disrupted in some way among psychopathic individuals [95,96]. Further work will be necessary to document the possibility of multiple, interactive, cognitive-affective dysfunctions in psychopathy [97,98] (see Outstanding questions). Psychopathy is a complex psychiatric disorder and models explaining associated behavior should be advanced to adequately capture that complexity.

Declaration of interests

The authors declare no conflicts of interest.

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