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Frozen in (e)motion: how reactive motor inhibition is influenced by the emotional content of stimuli in healthy and psychiatric populations

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Abstract

Efficient inhibitory control is vital. However, environmental cues can influence motor control especially in an emotional context. One common task to measure inhibitory control is the stop-signal task (SST), which asks participants to respond to go stimuli knowing that on some trials a stop signal will be presented, requiring them to inhibit their response. This paradigm estimates the ability to inhibit already-initiated responses by calculating participants' stop-signal reaction times (SSRT), an index of inhibitory control. Here, we aim to review the existing, often contradictory, evidence on the influence of emotional stimuli on the inhibitory process. We aim to discuss which factors may reveal an interference as well as an advantage of emotional stimuli on action inhibition performance. Finally, we review the existing evidence that has investigated the effect of such stimuli on action inhibition in the psychiatric population. Important factors are the relevance, the intensity and the valence of the emotional stimulus, as well as the affected component of the motor control. From all this evidence, it is clear that understand precisely how emotion is integrated into core executive functions, such as inhibitory control, is essential not only for cognitive neuroscience, but also for refining neurocognitive models of psychopathology.

Keywords: action inhibition; stop signal task; emotional stimuli; psychiatric disorders.

Introduction

Efficient interruption of ongoing actions is fundamental to prevent the execution of an undesired behavior. Often mentioned examples of such behavior include driving towards a crossroads, where the choice of executing or withholding an action (acceleration or braking) must be quick and should incorporate all information available. However, it is well documented that affective states may profoundly affect cognitive functions (Dolcos et al., 2017; Harlé et al., 2013; Tyng et al., 2017) and action control. Referring to the example above, a strong emotion of anger might interfere with the celerity of the choice of accelerating or braking. The ability to inhibit already-initiated actions can be investigated using stop-signal tasks (SST), designed to provide a sensitive measure of the time required by the brain to inhibit or suppress inappropriate motor responses (Lappin & Eriksen, 1966; Logan et al., 1984; Verbruggen et al., 2019; Vince, 1948). In this task, participants are requested to respond to a specific type of stimuli (i.e., “go” stimulus). However, sometimes, the go stimulus is followed by a “stop” signal that requires participants to withhold the ongoing action. The time between the “go” stimulus and the “stop” signal may be variable and modulated by the participant’s performance and is termed ‘stop signal delay’ (SSD). To measure the participant’s performance on the SST, the stop signal reaction time (SSRT), an index of inhibition, is computed based on Logan and Cowan’s notion (Logan et al., 1984). Estimated SSRT provides a measure of the duration of the inhibitory process by revealing how long it takes for successful motor inhibition (Fonken et al., 2016; Mattia et al., 2012; Mirabella et al., 2011). Critically, motor inhibition will be successful only when the SSD is short enough to allow inhibitory processes to brake the ongoing motor program, while larger SSDs will result in an increased likelihood of failure to inhibit the response (Bissett et al., 2021).

It is generally assumed that emotion is detrimental to cognition (De Houwer & Tibboel, 2010; Dennis et al., 2008; Hartikainen et al., 2000; Padmala et al., 2011). Indeed, fear-related stimuli lead to slower response times across a variety of tasks, even when emotion is task-irrelevant (e.g., Algom et al., 2004; Erthal et al., 2005; Hartikainen et al., 2000; Kuhn & Tipples, 2011). However, emotions are able to both enhance or hinder various aspects of cognition and behavior, demonstrating a complex influence of emotions on several cognitive processes (Dolcos et al., 2017; Harlé et al., 2013; Tyng et al., 2017). The *attentional account* (Schimmack, 2005) posits that emotional stimuli capture attention and hence disrupt performance in various executive tasks, as well as in simple discrimination tasks (Buodo et al., 2002; Hartikainen et al., 2000). This emotional interference is supposed to drain attentional resources from the voluntary allocation of attention in the primary task (i.e., the successful action inhibition) (Pessoa, 2009; Pessoa et al., 2012). Thus, according to this account, longer SSRT, reflecting poorer action control, are expected in an SST using emotional stimuli, since successful inhibition depends on the availability of attentional resources.

On the other hand, the *freezing account* posits that emotional stimuli induce a temporary freezing of all ongoing activities. Freezing is assumed to have an important evolutionary advantage because it allows for quick responses to stimuli that are potentially important for survival (Flykt, 2006; Öhman, Flykt, et al., 2001). In line with this account, greater action control should be possible when emotional stimuli are presented in an SST and in turn translate into shorter SSRT.

Indeed, stronger attentional capture and deeper processing for negative stimuli have been demonstrated by electroencephalographic (EEG) studies. These studies show that fearful and angry expressions entail a special processing advantage in being analysed rapidly in the brain (< 200 ms) that parallels the structural encoding of faces and bodies (Borhani et al., 2016; Eimer et al., 2009; Eimer & Holmes, 2002; Kawasaki et al., 2001; van Heijnsbergen et al., 2007; Vuilleumier et al., 2001), and elicits fast autonomic responses (Ellena et al., 2020; Globisch et al., 1999; Öhman & Soares, 1994). Studies measuring RTs have also demonstrated that negative emotional expressions draw attention rapidly and involuntarily (Holmes et al., 2003; Öhman, Lundqvist, et al., 2001) and, at the same time, induce early (70-150 ms) modulation of corticospinal excitability (Borgomaneri et al., 2014, 2017; Borgomaneri, Vitale, & Avenanti, 2015; Borgomaneri, Vitale, & Gazzola, 2015; Borgomaneri, Vitale, et al., 2020; Vicario et al., 2017), which has been interpreted as a freezing-like motor reaction (Borgomaneri, Vitale, & Gazzola, 2015).

Yet, both enhancement and impairment of response inhibition by emotions have been reported in using the SST. In an attempt to solve this issue, in 2009 Pessoa proposed the *dual competition framework*, which assumed that the emotional content influences both perceptual and executive control processes and that the intensity of the emotion plays a crucial role in defining the effect on cognition. Task-relevant stimuli of mild intensity improve executive control since they increase goal-directed behavior, whereas high intensity stimuli attract resources available for the task and hence disrupt executive processes. The idea of shared resources implies that cognitive and emotional systems share processing resources, without sharing processes per se. By contrast, Gray (Gray, 2004; Gray et al., 2002) argued that cognition and emotion are strongly integrated becoming inseparable during the information processing. According to this *integration account*, it is assumed that a certain emotional state may bias our behavior, adapting the cognitive system to situational needs. Therefore, the cognitive processes that are consistent with the situational demands can be facilitated, whereas other cognitive processes that are not relevant to the situational demands are impaired.

The endeavour to understand the relationship between action inhibition (SST) and emotion in humans originated approximately 15 years ago; here we review the major advancements, often contradictory, about the interplay between inhibitory control — a key component of executive control — and the process of emotional stimuli. It is important to mention that inhibitory control is not a single executive function. Instead, it encompasses several different components, e.g., motor and interference (or cognitive) inhibition (Mirabella, 2021). In their turn, these components have two domains: reactive and proactive inhibition. However, SST studies investigating the relationship between action inhibition and emotion perception have mainly tested reactive inhibition, thus, we focused our review on this component.

Our aim is to try to highlight other important factors, besides the stimulus intensity, that may contribute to the differential modulation of action inhibition capabilities. Here, we will firstly present evidence supporting the idea that emotional stimuli interfere with response inhibition, and afterwards, contrasting evidence supporting the idea that emotional stimuli facilitate response inhibition. Moreover, maladaptive emotional processing and deficient emotion regulation, as well as deficient inhibitory control are core factors in different psychopathologies, such as schizophrenia (e.g., Enticott et al., 2008), obsessive-compulsive disorder (Chamberlain et al., 2006; Mancini et al., 2018; Mirabella et al., 2020), and bipolar disorder (Houshmand et al., 2010). Therefore, disentangling how action control interfaces with emotion processing would open a new window upon the pathophysiology of a series of psychopathologies. In light of this notion, the final part of this review will focus on the interplay between psychiatric disorders and action inhibition abilities on facing emotional stimuli.

Emotional stimuli interfere with response inhibition

One of the first studies that investigated the effect of emotional stimuli on the covert ability to withhold an action was carried out by Verbruggen and De Houwer in 2007 (see Table 1). During the SST participants were presented with an emotional scene followed by one of two abstract stimuli that participants had to discriminate. A sound was used as an auditory stop signal. Importantly, in order to disentangle whether the arousal or the valence dimension could explain the impact of emotional stimuli on the action inhibition performance, in a first experiment, positive and negative stimuli were matched on arousal and were compared with low arousing neutral pictures. In a second experiment, valence and arousal were manipulated orthogonally. Results from the first experiment showed longer SSRT for trials in which emotional stimuli (both positive and negative) were presented compared to neutral trials, suggesting that arousing stimuli may have captured participant's attention and consequently, interfered with their ability to inhibit an action. Experiment 2 further clarify this phenomenon by showing that SSRT were prolonged after seeing high-arousal pictures (both positive and negative) compared to low-arousal pictures (both positive and negative). These results support the idea that high arousing stimuli capture attention away from the ongoing activities disrupting action control. Krypotos and collegues (Krypotos et al., 2011) tried to replicate these findings by additionally testing the hypothesis that individual differences in emotion regulation (i.e., high or low level of heart rate variability - HRV) may affect the way in which emotions impact on cognition. Better inhibition performance (shorter SSRT) was found in participants with high levels of HRV compared to participants with low levels of HRV. A subsequent fMRI study (Sagaspe et al., 2011), investigated the neural basis of action control, when negative (fearful face) or neutral (facial) stimuli are used as stop signals. The task was to discriminate the gender face, to ensure that the emotional information was incidental to the task. Crucially, participants were also instructed to inhibit their action in response to changing colors of the surrounding frame. Analysis of RTs of unsuccessful stop trials revealed slower responses to fearful than neutral faces, suggesting that inhibition processes activated by stop signals could interact with emotional processing to further slow down motor responses in fear compared to neutral trials, even when such inhibition eventually failed to cancel motor execution. However, SSRT data did not reveal any significant effect, indicating that action control was not influenced by the emotional information. Brain imaging data collected in this experiment revealed that, according to behavioral data (i.e., slower RTs in fearful stop trials), activity in the primary motor cortex was lower when incorrect responses were made on stop signal trials in which the stop was a fearful face, compared to neutral. Moreover, successful motor inhibition to threat signals increased activation in limbic regions (i.e., amygdala), in the supplementary motor area (SMA), in a region in the lateral orbitofrontal cortex, distinct from areas in the inferior frontal gyrus typically associated with voluntary inhibition (Aron et al., 2003; Borgomaneri, Serio, et al., 2020; Chevrier et al., 2007; Leung & Cai, 2007; Zhang et al., 2017). Importantly, the right IFC responses were reduced on successful stops for the fearful compared to neutral faces, suggesting that the right IFC might not be directly responsible for successful inhibition in response to emotional stimuli.

In the same year, Herbert & Sütterlin, 2011 tested whether the effect of negative emotional stimuli can be observed earlier than proposed by Verbruggen and De Houwer (2007), in line with EEG findings which suggested that negative stimuli are processed as early as 200 ms after emotional stimulus onset (Pourtois et al., 2004; Schupp et al., 2003). Moreover, the authors argued that the detrimental effect that emotions exert on action control suggested by Verbruggen and De Houwer, 2007 should generalize across different categories of stimuli. To test their hypothesis, the authors presented verbal material (i.e., pleasant, unpleasant, and neutral nouns) to which participants were asked to respond. In the stop-trials, an acoustic stop signal informed participants to inhibit their response. Indeed, to test a possible earlier effect of negative stimuli, stimulus onset asynchrony (SOA) between the acoustic stop-signal and noun-onset was 150 ms, 200 ms and 250 ms. RTs in go trials were significantly longer for unpleasant and pleasant compared to neutral nouns but did not differ significantly between unpleasant and pleasant nouns. SSRT was found to be modulated by SOA: only for the 250 ms SOA, was SSRT significantly enhanced for emotional compared to neutral nouns. These results support the attentional account and, additionally, they demonstrate that the attentional capture exerted by the emotional stimuli can have an earlier impact on action control than was previously thought. However, these results fail to show an effect in earlier SOAs as suggested by EEG studies on visual ERP components, confirming that the emotional stimulus may be processed later by the motor system, when action inhibition is required. Using a paradigm similar to the one used by Verbruggen and De Houwer, 2007, Kalanthroff and colleagus (2013) presented negative and neutral scenes, while an auditory stop signal was used to inform participants to interrupt their action. In line with previous findings, RTs and SSRT for negative stimuli were significantly longer than for neutral stimuli. These data support the notion that emotional negative stimuli are able to capture attention and may induce a momentary cognitive freeze, thus impairing responding and inhibitory control, in line with those of other studies that found reduced performance in executive tasks following emotional stimuli (e.g., Dennis et al., 2008; Padmala et al., 2011). In order to further replicate this effect, Rebetez and colleagues (2015) asked participants to categorize the gender of a facial expression of joy, anger or neutral and to withhold their response when a tone was presented as stop. SSRT was prolonged in negative trials compared with neutral and positive trial, the latter, in turn, being prolonged compared with neutral trials. This data supports previous findings and additionally demonstrated that greater interference was observed for negative valence than for positive valence, which corroborated previous studies showing that positive stimuli capture attention less than negative stimuli do (therefore producing less interference in the ongoing task; see Baumeister et al., 2001). To go a step further (Yu et al., 2012) investigated possible gender differences in action inhibition when highly arousing erotic and painful stimuli are presented. Participants were required to respond to a directional arrow probe, and withhold their response when they saw a stop signal (i.e., an abstract cue). Erotic images or clips of physical pain matched for valence and arousal or control stimuli were shown to participants shortly before each trial. Male participants selectively showed slower SSRT both when viewing erotic and pain pictures relative to the control condition. These results suggest that male participants are more susceptible to general emotional interference than female participants, while in the erotic session, both men and women's go RTs increased significantly, suggesting that erotic stimuli are able to capture the attention of both sexes. In an attempt to assess whether such effect can be modulated by the awareness of being observed, the same authors (Yu et al., 2015) replicated the previous study (Yu et al., 2012) and found that the impairing effect (i.e., slower SSRT in male participants for erotic compared to neutral images) was completely eliminated when participants were led to believe that they were monitored by a webcam, while female participants were not affected by emotional content nor by the context of the SST. This effect suggests that it is possible to reduce the emotion's impact on cognitive processes by simply modulating the context in which the action control takes place. Interestingly, high cognitive control abilities are found to impact also on the ability to trigger a stable romantic relationship, by suppressing the desire to approach another person (Pronk et al., 2011). Moreover, romantic love has been shown to provide resiliency against the adverse impact of negative emotion (Nilakantan et al., 2014; Schneiderman et al., 2011). Therefore, Song and coworkers (Song et al., 2016) explored the impact of the duration of a love relation (i.e., early stage and longer periods of love) on the ability to action inhibition with emotional cues. To do so, the authors asked participants to perform an emotion discrimination task, presenting sad or neutral facial stimuli, except when a stop signal appeared. In line with all the previous findings, longer SSRT was found in the emotional compared to the neutral trials. Interestingly, such effect was affected by the fact of being or not in a love relation as well as by the stage of the relation: SSRT for emotional stimuli was significantly shorter in the in-love group compared to single participants, while SSRT for neutral stimuli did not show any across group differences. Concurrently, while single participants showed shorter SSRT for emotional stimuli compared to the SSRT for neutral trials, the in-love participants showed similar SSRT across emotional and neutral stimuli. Moreover, significantly shorter SSRT in emotional trials were observed in early stage lovers compared with both individuals who were in a romantic relationship for a long time as well as single participants. This data suggested that individuals who are in a recent relationship may have more self-control and thus attenuating the effect of negative emotion perception on action control.

To investigate more deeply how the neural bases responsible for successful action inhibition (Borgomaneri, Serio, et al., 2020) are affected by emotional stimuli presentation, the same authors (Ding et al., 2020) tested the potential interference effect of sad facial expressions on response inhibition using an SST combined with functional magnetic resonance imaging (fMRI). Female participants were involved in an emotion discrimination task and were asked to inhibit their response if a stop signal occurred after the face stimuli. Results confirmed that compared with neutral stimuli, sad stimuli produced longer SSRT, indicating worse response inhibition. Moreover, compared with the neutral condition, higher activation during the sad condition was found within several regions involved in action control (i.e., the right superior frontal gyrus (SFG), right insula, right middle cingulate cortex (MCC), bilateral superior temporal gyrus (STG), left lingual gyrus, and right motor cortex). These data indicated that sad stimuli specifically modulated the neural activity in brain regions associated with the combined process of emotion regulation and action inhibition. In line with these findings, Patterson and colleagues (Patterson et al., 2016) found a modulation of the neural activity in areas devoted to action control, following negative image viewing. Before the SST, an image-viewing task inside the scanner was performed in which participants were presented with negative or neutral images and had to rate their level of distress. Following this task, participants performed the SST, by indicating the direction of arrows and were asked to inhibit their answer when the arrow was presented along with an auditory cue. Results from the image-viewing task confirmed that negative image viewing successfully induced distress and the presentation of such negative stimuli prior to the SST decreases stopping-related neural activations and decreases functional connectivity between the right IFG and other areas of the cerebral cortex and cerebellum. However, no effect of negative image viewing was detected either in the SSRT or in the RTs. In a second behavioral experiment, the authors introduced a reappraisal condition, in which participants viewed negative images and were instructed to internally produce captions for the images. Collapsing the two negative conditions (i.e., with or without reappraisal), SSRT was significantly longer in the negative than the neutral condition. These data nicely demonstrated that distressing memories may impact on action inhibition capabilities even when the negative stimuli are no longer present, demonstrating that negative emotional stimuli produce strong and resistant carry-over effects on executive functions.

Together, these evidences (see Table 1) demonstrated that emotional stimuli may be detrimental to the ability to control our motor responses, especially when these emotional stimuli are irrelevant for the SST (i.e, the emotional stimulus is presented before the go stimulus) (Kalanthroff et al., 2013; Krypotos et al., 2011; Verbruggen & De Houwer, 2007). However, mixed results were reported if the emotional stimulus is presented as go stimulus (but always task-irrelevant) (Rebetez et al., 2015; Sagaspe et al., 2011; Williams et al., 2020). The abovementioned findings are compatible with a *resource competition model*, by which executive functions and emotions are thought to compete for the same resources (e.g., Garofalo et al., 2019, 2021; Pessoa, 2009). A second possibility is that after viewing negative stimuli, prefrontal cortex-dependent resources that would normally be allocated to response inhibition are recruited for threat detection. In support of this latter interpretation, fear conditioning studies indicate that several prefrontal regions involved in response inhibition are also involved in responding to stimuli that have been previously paired with an aversive unconditioned stimulus (Battaglia et al., 2018, 2020; Borgomaneri, Battaglia, et al., 2020; Borgomaneri, Battaglia, Sciamanna, et al., 2021; Fullana et al., 2016; Harrison et al., 2017).

Please Insert Table 1 near here

Emotional stimuli facilitate response inhibition

All the aforementioned studies showed a general detrimental effect of emotion on cognitive control abilities, measured by means of the SST. However, other evidence suggest that emotion can facilitate cognitive performance (see Table 2). The impact of emotion on cognition was hypothesized to depend on the intensity of the emotional information (Pessoa, 2009). Stimuli of mild intensity were proposed to enhance sensory representation and thereby improve behavioral performance when relevant for the task. In contrast, high-arousal stimuli (e.g., threat of shock, erotica) were proposed to generally impair task performance, by subtracting attentional resources that are required for task execution. To test this possibility, Pessoa and colleagues (2012) evaluated the impact of emotional low-intensity stimuli (faces) on response-inhibition performance (experiment 1), while in a second experiment, the authors assessed the impact of more intense emotional stimuli (auditory stimuli paired with mild electric shocks) on response-inhibition performance. In experiment 1, a geometric shapes discrimination task was employed in which neutral, happy, and fearful faces were used as stop stimuli. SSRT was found to be affected by the emotional content, so that shorter SSRT was recorded in both fearful and happy conditions compared to neutral ones, while no significant difference in SSRT was found between the happy and fearful conditions. These data suggest that participants were better at inhibiting the responses when emotional arousing stimuli were presented, suggesting that the arousal component of the faces interacted with inhibitory processes rather than the valence component. The authors also reported a positive correlation between anxiety and SSRT facilitation for negative emotional stimuli, so that subjects with higher trait anxiety showed larger inhibitory performance improvements during the fearful (relative to neutral) condition. In the second experiment, auditory stimuli were used as stop signals instead of faces. Such auditory stimuli were fear conditioned prior to the SST, so that one of these tones was previously paired with shock pulses (CS+ stop signal) while the other tone was never paired without any aversive consequences (CS- stop signal). Although no shocks were delivered during the SST, participants had learned that the CS+ tone was highly aversive, while the other was considered neutral. In line with the idea that the salience of the stop signal may influence the effect of emotional stimuli, SSRT was longer during the CS+ condition compared to the CS− condition, demonstrating that it was harder to inhibit the behavioral response during the former highly arousing condition. Here, no correlation was found with anxiety traits. This second study is in line with those reported in the previous section, indicating that the processing of the threatening/arousing stimulus consumed processing resources that were needed for successful inhibitory performance. The first experiment instead found opposite results demonstrating a beneficial effect of emotion on cognition. The authors interpreted these opposite effects as suggesting that emotion can either enhance or impair cognitive performance, likely as a function of the emotional saliency of the stimuli involved. Indeed, stop signals of different intensities may reveal separable mechanisms contributing to the observed behavior.

In an attempt to study how emotional visual stop signals affected both response inhibition and error monitoring, Senderecka (2016) performed an SST task while EEG was recorded in which participants had to discriminate the direction of an arrow, except when an emotionally negative or neutral picture was presented as a stop signal. Behavioral results were in line with the first experiment in Pessoa et al., 2012, with shorter SSRT in the emotional condition, indicating that participants were better at inhibiting their responses when the emotional stimuli were task-relevant. However, in contrast to Pessoa's findings, no significant correlation was observed between trait anxiety and behavioral performance. The enhanced inhibitory performance had no effect on inhibitory processing at the electrophysiological level (N2–P3 complex). However, the perceptual processing of threatening stop signals resulted in larger and earlier N1 and Pe components, associated with conscious evaluation or affective processing of an error. As suggested by the *dual competition framework*, these results support the hypothesis that threatening arousing stimuli improve behavioral inhibitory performance and error monitoring due to the enhancement driven by perceptual processing (Pessoa, 2009). In a subsequent study, the same author (Senderecka, 2018) aimed to test whether their previous findings can be generalized to emotional stimuli from a different sensory modality (e.g., auditory). To reach this goal, an SST requiring response inhibition to aversive and neutral auditory stimuli was used. In line with her previous findings, SSRT was significantly shorter in the emotional than in the neutral condition, confirming that participants were better at inhibiting the responses even when the emotional stimuli were auditory. These data are in line with electrophysiological findings, which demonstrated higher processing and conscious error monitoring for aversive sound (larger N1, P3, and Pe components). However, task performance can be enhanced under threat circumstances because cognitive processing is prioritized by the threat (Gray et al., 2002). To investigate this hypothesis, Choi & Cho (2020) asked participants to perform an SST under safe or threat circumstances (i.e., participants were aware about the possibility of receiving an electric shock). The go stimulus was either a white circle or square, while the stop signal was red filled in a target stimulus. Results showed that SSRT was shorter under threat of shock than under safe conditions, indicating that the inhibitory process of ongoing responses was more efficient under the former. The mean RT was longer in threat blocks than safe blocks on correct go trials, indicating that visual discrimination was impaired under threat circumstances. Finally, an inverse relationship with SSRT difference between threat and safe conditions and anxiety was found selectively in the threat blocks, implying that participants with higher scores in state anxiety were more likely to withhold their responses than those with lower scores when the shock was anticipated.

Taken together, these findings demonstrated that emotional stimuli may also enhance action inhibition, especially if the stop stimulus is not very threatening/arousing (Pessoa, 2009).

Please Insert Table 2 near here

Emotional stimuli and response inhibition in psychiatric populations

The ability to voluntarily inhibit unnecessary actions is an important aspect in psychiatric disorders. Indeed, deficits in action inhibition were identified in different psychopathological conditions, including schizophrenia (Tsujii et al., 2018; Yang et al., 2020; Yu et al., 2019), bipolar disorder (Farahmand et al., 2015; Hidiroğlu et al., 2015), attention deficit hyperactivity disorder - ADHD (Janssen et al., 2015; Senderecka et al., 2012), Parkinson's disease (Di Caprio et al., 2020; Mirabella et al., 2017), substance use disorders (Smith & Mattick, 2013; Wang et al., 2018) and obsessive-compulsive disorder (De Wit et al., 2012; McLaughlin et al., 2016; Sohn et al., 2014; for a meta-analysis see Lipszyc & Schachar, 2010). However, there are also studies that report contradictory results or that ascribed the poor inhibitory control observed in psychiatric patients to more generalized attentional and/or cognitive problems (Alderson et al., 2007; Elton et al., 2014; Kalanthroff et al., 2017; Li et al., 2008; Lyche et al., 2010; Matzke et al., 2017; Weigard et al., 2019). Moreover, everyday contexts are characterized by relevant emotional aspects that can significantly modify the ability to withhold inappropriate actions. These aspects are particularly destabilizing for the great majority of psychiatric conditions, where emotions are often perceived as disruptive. It is no coincidence that a defective ability to perceive and/or regulate one's or others' emotions is present within the DSM-5 diagnostic criteria of many psychiatric conditions (e.g., Autism Spectrum Disorder) (American Psychiatric Association DSM-5 Task Force, 2013). For these reasons, several works have focused on the study of motor inhibition using the SST with emotional stimuli, or by inducing an emotional state before carrying out the SST in psychiatric populations (see Table 3).

In one of the first studies that used these paradigms (Lau et al., 2007), individuals with a major depressive disorder, non-depressed anxious controls and healthy participants, performed an SST in which words with positive, negative and neutral valence, and non-words were presented. Participants were asked to perform a lexical discrimination task, and to withhold their response when an auditory tone was presented. Longer RTs were observed in all groups for responding to negative compared to neutral words, while no emotional effect was found for the SSRT.

In a later work, Aker and coworkers (Aker et al., 2014) compared the performance of previously depressed women and never-depressed women in an emotional version of the SST, in which a picture of a neutral or an angry expression was presented before the go stimulus. An auditory signal was used as stop signal. No effect on SSRT was observed and the authors ascribed this null effect to the low intensity of their stimuli. In order to investigate this issue more deeply, Camfied and colleagues (Camfield et al., 2018) tested depressed participants in an SST during EEG to test brain components of action inhibition. Previous electrophysiological studies of response inhibition have revealed that the frontal-midline NoGo-N2 (200–400 ms) event-related potentials (ERPs) are modulated by the competition between response execution and inhibition (Donkers & Van Boxtel, 2004; Yeung et al., 2004) and the NoGo-P3 (300–600 ms), which is more specifically related to motor inhibition (Huster et al., 2013; Smith et al., 2008). A neutral, positive or negative scene was presented within a blue or a green frame. Participants were required to discriminate the color of the frame, except when an auditory tone was presented (stop signal). As previously reported, SSRT was not found to be affected by image category nor depression status. However, the electrophysiological data showed a reduced NoGo-N2 component for positive images, whilst the NoGo-P3 component was reduced for both positive and negative images in comparison to neutral images. This effect was found to be enhanced for the depressed participants, indicating that inhibitory processing in the context of positive stimuli may be more decreased in depressed patients than in healthy controls. In contrast to the SST study conducted by (Senderecka, 2016), the current study used an indirect SST task where the stop signal was presented in the auditory modality and the emotional images themselves were not used as stop signals. To sum up, to date it is still not clear whether and how depression may affect action inhibition, and thus, future studies are needed to shed light on this issue. Investigating the inhibitory process in depression is relevant as depression is inherently linked with suicide ideations or self-harm (Omary, 2021), which represent two of the most dangerous and pathological behaviors. Although no significant differences were found between self-injured and non-self-injured individuals in motor inhibition using classical SST (Glenn &

Klonsky, 2010), these destructive behaviors often occur as a result of negative emotion. Thus, Allen & Hooley (2015) tested self-injuring individuals and healthy controls in an SST in which positive, negative and neutral images were presented, together with images depicting acts of self-harm. These pictures served as a go signal and participants had to discriminate their valence, while an auditory tone was occasionally presented as a stop signal. Both groups made more errors in suppressing motor responses when facing positive and negative images compared to neutral ones. Additionally, self-injuring participants made more errors in inhibiting responses for negative images than the control group. Finally, self-injuring individuals made fewer response inhibition errors for images representing self-harm compared to the control group. Basically, self-injuring participants did not show a general deficit of motor inhibition, as evidenced by the lack of significant differences between groups in SSRT. However, it is possible that self-injuring individuals have greater difficulty in suppressing actions when facing negative emotions, as shown by the different performance between groups in stop-trials with negative images. In contrast, self-injuring patients made fewer errors than the control group with self-harm images, thus showing better inhibitory control. In this regard, it is possible that self-injuring participants have learned to associate the stimuli related to self-harm with a relief or a reward, or that these stimuli are merely more familiar to them. Also, suicide attempts are likely to be linked to impulsivity in threatening contexts and negative emotional states. Understanding the characteristics that distinguish ideators from suicide attempters is an important research question, which is still unsolved. A previous study (Millner et al., 2020) found no difference between suicide ideators and suicide attempters using classical SST. Hence, in a recent study, You and colleagues (You et al., 2020) tested participants who had attempted suicide, suicide ideators, and healthy controls with emotional SST. Emotional faces of anger and happiness were presented in a context of threat, and emotional faces of sadness and happiness in a safe context. Participants had to judge the valence of the presented face, while an auditory stop signal was used as a signal to withhold their response. Results showed longer RTs for negative emotions than for positive ones, and this effect was greatest in the context of threat.

Furthermore, only healthy participants showed shorter SSRT in the threat context in response to positive versus negative faces. No significant differences in SSRT were found for the non-threatening context. Thus, both suicide ideators and attempters showed impairment with respect to positive stimuli only in the context of threat unlike non-suicidal controls. In other words, it seems that ideators and attempters have difficulties in processing positive information in a threatening context. However, no differences were found between ideators and attempters under an emotional context.

In a recent study by Legrand & Price (2020), a group of individuals with a history of substance use disorder were tested with an emotional SST in which happy, angry and neutral facial stimuli were presented. The task required participants to discriminate the gender of a face while an auditory tone was used as a stop signal. In addition, participants were classified based on their levels of depression and anxiety. Results showed longer SSRT for negative faces than neutral ones.

Highly depressed participants showed longer SSRT, indicating lower ability in action control. Low depressed participants exhibited slower SSRT to positive and negative faces than neutral ones. Conversely, in participants with low levels of anxiety, SSRT was longer for negative and positive faces than for neutral ones. These data demonstrate that depression and anxiety levels are able to modulate the impact of emotion on cognition.

Another psychiatric nosographic diagnosis that attracted much interest is bipolar disorder. Bipolar disorder is characterized by alternation of episodes of depression and mania, with a risk of suicide that is estimated to be at least 15 times that of the general population. Furthermore, in this context is important to stress that individuals with bipolar disorder manifest a cognitive impairment that persists even during euthymic (i.e., normal mood) periods. A correct understanding of the influence of emotions, which are critically disruptive in this disorder, on their inhibitory abilities is thus pivotal to plan successful cognitive therapies and appropriate social support. Houshmand and coworkers (2010) tested euthymic patients with bipolar disorder, their healthy siblings, and healthy controls, in an SST after induction of a relaxed mood state and intense sadness. Then, the SST was carried out, presenting words with pleasant or unpleasant emotional content, and asking the participants to discriminate their valence. Occasionally, an auditory tone was presented as a stop signal. Longer RTs and SSRT were observed in all groups for words with unpleasant emotional content compared to words with pleasant content. Furthermore, bipolar patients had longer RTs and SSRT than controls regardless of the words valence and the emotional state induction. In particular, bipolar patients had longer RTs when they were in a relaxed state than healthy controls in both emotional conditions. Instead, when bipolar patients were in the sad mood state, no significant differences were found compared to the other groups. Furthermore, healthy siblings showed a non-significant trend of longer RTs when they were in the sad mood state than controls under relaxation. For the SSRT, bipolar patients showed worse inhibition performance in the sad mood state compared to healthy controls in both emotional conditions. Finally, the healthy siblings showed a non-significant trend of longer SSRT under relaxation compared with relaxed healthy controls. The authors suggest that bipolar patients require a high level of emotional arousal to react as fast as healthy controls, and this would be demonstrated by the RT results. On the contrary, bipolar patients poorly performed in a sadness emotional state. Therefore, the results of this work confirm previous observations of emotional vulnerability in bipolar patients (Henry et al., 2008; M'Bailara et al., 2009) and additionally support the idea that emotions impact on action control in these patients.

Poor inhibitory control is well documented in schizophrenia, and the performance of these patients quantified with SSRT correlated with decreased activation in right IFG (Hughes et al., 2012), a crucial area in inhibitory control (Borgomaneri, Serio, et al., 2020). However, only a few studies have tested emotional SST in these patients. Derntl & Habel, 2017 tested schizophrenic patients in a SST presenting emotional (anger) and neutral faces surrounded by a white frame to which participants were instructed to respond. However, when the frame turned yellow the motor response had to be withheld (stop signal). Results showed that patients made more errors in neutral trials compared to the control group, while no difference was found for emotional trials between groups. Both groups had shorter SSRT for angry stimuli compared to neutral stimuli, suggesting an emotional facilitation effect also in schizophrenic patients. Regarding the lower accuracy of patients in neutral trials, according to the authors it is possible that the ambiguity of neutral faces stimulated false interpretations that interfered with the ability to inhibit the response. In order to further investigate the role of emotions in action inhibition in schizophrenia, Zheng and colleagues (Zheng et al., 2020), tested behavioral performance in a group of schizophrenic patients in an SST that included positive, negative and neutral stimuli. Participants had to detect the shape of the frame (i.e., curly or straight), while they had to stop responding if one of the images was presented inside the frame. So, unlike (Derntl & Habel, 2017), the stop signals were the emotional images themselves. Patients showed longer SSRT compared to the healthy control group. For both groups, SSRT were longer for the negative pictures compared with the positive and the neutral pictures, and there was no significant difference between positive and neutral pictures. Lastly, patients made more errors in trials following negative images than controls, but not after neutral and positive trials. In line with previous results (Lipszyc & Schachar, 2010; Wright et al., 2014), this study showed that schizophrenic patients have an overall impairment of response inhibition, without being affected by the emotional content (i.e., negative images improved the patients' motor inhibition in a similar way to the controls, consistent with the findings of Derntl & Habel, 2017). Finally, the worse performance for negative images (i.e., more errors) has been hypothesized to be a consequence of the faster attentional disengagement shown by schizophrenic patients compared to control subjects for unpleasant stimuli (Strauss et al., 2011). In summary, generalized inhibition deficits do not necessarily occur in psychiatric disorders, but more specifically they would emerge in response to particular stimuli and/or emotional contexts. Furthermore, it is also possible that emotional stimuli attenuate differences in motor inhibition between patients and healthy controls. The variability of the effect of emotions on motor inhibition in psychiatric patients could depend on numerous factors, including the characteristics of the different psychiatric disorders, the use of emotional or neutral go and stop signals (both auditory or visual), the valence of emotional stimuli, the level of arousal elicited by the stimuli, and the context in which the stimuli are presented. Indeed, the heterogeneity of results could be explained by the fact that the correspondence between poor impulse control and a generic deficit in inhibitory control is untenable (Mirabella, 2021). Inhibitory control has several components (motor and interference inhibition) and subdomains (reactive, proactive, and automatic inhibition). Besides, peculiar impairments in inhibitory control characterize different pathologies. Therefore, future studies need to take into consideration all these factors when planning SST experiments in psychiatric samples.

Please Insert Table 3 near here

Discussion

Understanding how emotions can improve or disrupt our motor inhibition ability is a crucial issue both for a deeper knowledge of the mechanisms underlying executive functions and to design targeted and effective interventions for the treatment of several psychiatric disorders. Indeed, emotions are a fundamental part of everyday contexts and of the adaptive challenges necessary for selecting the appropriate behaviour in a social environment. As already mentioned, various psychopathological and psychiatric conditions are characterized by serious impulsivity problems that contribute to determining disability due to poor regulation and control which can worsen in the presence of emotional cues, leading to dramatic behavioral consequences. Despite the evident exigency to test the interaction between emotions and action control, to date very few studies have directly addressed this issue, especially in psychiatric populations.

The few existing studies have often reported contradictory findings. One aspect that may have contributed to the contrasting results is the different experimental paradigms adopted across SST studies. Experimental paradigms may differ in the role of the emotional stimulus (e.g., as stop signal, go signal, or presented prior to the go signal), but also in the relevance of the emotional stimulus for the SST. Indeed, in the SST the emotional stimuli can be task-relevant (i.e., requiring the explicit discrimination of the go emotional stimuli (e.g., Ding et al., 2020) or task-irrelevant (i.e., the emotional cues are implicitly perceived) (e.g., Sagaspe et al., 2011). Hence, in order to disclose whether the task relevance of the emotional stimuli may have contributed to the different findings, Mirabella (2018) and Mancini and coworkers (2020) undertook to directly compare these two conditions. Evidence highlighted that when the role of emotions was task-relevant, behavioral differences were found in a go/nogo task (i.e., worse performance for negative emotions) (Mancini et al., 2020; Mirabella, 2018), while no behavioral differences between emotional and neutral stimuli were detected when emotional stimuli were task-irrelevant. Consistent with these findings, the use of task-relevant emotional stimuli in SST produced similar results (i.e., worse inhibition capacity) for emotional cues used as go stimuli compared to neutral ones (i.e., longer SSRT; (Ding et al., 2020; Song et al., 2016), while an SST with task-irrelevant emotional stimuli as go signal produced mixed results in terms of inhibitory performance (Derntl & Habel, 2017; Pawliczek et al., 2013; Rebetez et al., 2015; Sagaspe et al., 2011). However, it should be noted that the differences in the results obtained with implicit SST could also be due to the task difficulty (Ding et al., 2020). Indeed, in implicit SST paradigms, shorter SSRT were obtained when the go task was simple (i.e., respond by pressing the same button to all stimuli) (Derntl & Habel, 2017; Pawliczek et al., 2013), while longer SSRT (Rebetez et al., 2015) or no difference in inhibition times (Sagaspe et al., 2011) were observed when the go task required a more complex discrimination (i.e., gender discrimination task). Another aspect that may be fundamental in determining significant differences in individuals' SST performance is the intensity conveyed by the emotional content of the stop stimulus (Pessoa, 2009; Pessoa et al., 2012). In general, an emotionally significant stimulus can determine a greater sensorial/perceptual representation conveyed by an attentional advantage (Carretié et al., 2004; Pourtois et al., 2013), with a consequent behavioral improvement. However, it is also possible that, given the sharing of resources between emotional and executive processing (Padmala et al., 2011), the need to process emotional stimuli may result in a lower availability of cognitive resources for the execution of the ongoing task, as supported by the *attentional account* (Schimmack, 2005). According to Pessoa (2009), powerful/intense emotional stimuli would lead to a worse motor inhibition by subtracting cognitive resources, while stimuli characterized by a milder emotionality would instead be able to improve task performance, by perceptual enhancement. In this regard, longer SSRT (i.e., worse inhibition performance) for powerful stop stimuli conditioned with electric shocks (Pessoa et al., 2012) have been observed, while shorter SSRT (i.e., better inhibition performance) have been observed with lower arousal stop stimuli, such as emotional faces, emotional images and negative acoustic stimuli (Pessoa et al., 2012; Senderecka, 2016, 2018). Finally, emotional stimuli presented prior to the go stimulus (i.e., in implicit emotional SST) led to longer SSRT than neutral stimuli (Kalanthroff et al., 2013; Patterson et al., 2016; Verbruggen & De Houwer, 2007), with higher arousal stimuli that resulted in longer SSRT than lower arousal stimuli (Krypotos et al., 2011; Verbruggen & De Houwer, 2007). This effect can be attributed to the attentional capture exerted by the emotional stimulus (Fox et al., 2001; Schupp et al., 2006; Wyble et al., 2008), which subtracted resources both from the go task (longer RT) and the inhibition task (longer SSRT) (Kalanthroff et al., 2013; Krypotos et al., 2011; Verbruggen & De Houwer, 2007). Another aspect that would require further investigation concerns the valence of the emotions. In fact, most SST studies have used exclusively negative emotions. However, a few studies have employed positive emotions in SST (Nayak et al., 2019; Pessoa et al., 2012; Rebetez et al., 2015; Verbruggen & De Houwer, 2007; Williams et al., 2020) and, interestingly, only Rebetez and colleagues (Rebetez et al., 2015) found different effects depending on the emotional valence of the go stimuli (i.e., stronger interference for negative relative to positive stimuli) when the emotion was not relevant to the go task. In contrast, Williams and colleagues found no difference when the emotion was not relevant to the task, while a facilitation effect for positive versus negative stimuli emerged when the go task involved emotion discrimination (Williams et al., 2020). In partial agreement with these findings, Nayak and colleagues (Nayak et al., 2019) found shorter SSRT for positive versus neutral stimuli but not versus negative, when emotional stimuli were task-relevant.

In conclusion, a relatively large body of literature demonstrates the key connection between emotion processing and action control. Yet, critical inconsistencies still hinder the full implementation of any translational research program towards psychiatric populations. Here following, we will offer a summary of the available evidence in these populations.

Although SST studies involving psychiatric populations are limited and do not allow to draw accurate conclusions, the SST performance in several patients may suggest some peculiarities in motor response inhibition. The SST studies with psychiatric patients with self-harming and suicidal tendencies (Allen & Hooley, 2015; You et al., 2020) observed that emotional stimuli may lead to different behavioral effects compared to healthy participants. For example, the presentation of extremely negative stimuli (i.e., pictures of self-mutilation) produced a similar performance to positive stimuli in patients (but different compared to control participants), although the patients themselves did not judge the self-injury images as positive. Instead, with regard to schizophrenia, we have already reported that several studies agree in considering the response inhibition as generally and greatly impaired in these patients (Ethridge et al., 2014). At the same time, however, it has been observed that negative emotional stimuli can lead to better inhibitory performance (i.e., shorter SSRT) in schizophrenic patients similar to that observed in healthy controls (Derntl & Habel, 2017; Zheng et al., 2020), suggesting the possibility to use emotional signals to facilitate cognitive functions even in the presence of psychopathological conditions. In depressed patients, on the other hand, through classical (i.e., non-emotional) SST impaired inhibition performance was observed (i.e., patients have longer SSRT than controls; Aker et al., 2015; Bredemeier et al., 2016), but no difference in SSRT between healthy and depressed patients was observed when using an emotional SST (Aker et al., 2014; Lau et al., 2007; see also EEG study by Camfield et al., 2018). Importantly, it should be noted that no explicit SST paradigms were used. In this regard, Ding and colleagues (Ding et al., 2020) suggested that the explicit paradigm should be the most appropriate for the clinical study of motor inhibitory behavior, since emotional stimuli directly represent the goal of the response inhibition, as in many ecological contexts. Furthermore, explicit SST showed higher sensitivity in recording the interference effect even when low arousing stimuli are presented (Ding et al., 2020; Song et al., 2016). Hence, using explicit SST may be useful for future studies involving psychiatric as well as healthy participants.

A further important limitation is the lack of SST studies testing anxious patients. Through go/nogo tasks it has been shown that patients with anxiety disorders exhibit excessive response inhibition leading to a maladaptive behavioral/performance effect (Grillon et al., 2017). Conversely, in healthy participants, a high level of state anxiety (shock-induced) improved performance at the go/nogo task (Robinson et al., 2012), while high trait anxiety showed no correlation with response inhibition (Li et al., 2008; Righi et al., 2009). These results are consistent with a recent SST work by Choi and Cho (Choi & Cho, 2020), in which the induction of a state of threat via electric shock delivery resulted in improved motor inhibition (i.e., shorter SSRT). Therefore, executive functions and related behaviors can be affected not only by the transient anxiety state but also in patients affected by pathological anxiety, such as specific phobia in which patients may show aberrant behavioral responses towards the phobic stimulus (Borgomaneri, Battaglia, Avenanti, et al., 2021). However, behavioral evidence of the impact of phobic/anxious stimuli is still lacking. Finally, two relevant questions that are extremely important to favor the translational application of SST are still devoid of an answer. First, it is still unexplored whether individuals at the earliest stage of psychiatric disorder (for instance, individuals who manifested the first psychotic episode) and individuals at ultra-high risk for psychiatric disorders (McGorry et al., 2009), especially psychosis, do manifest an effect on emotions on action inhibition. This knowledge will be of critical relevance to understand whether SST could be used to assist early diagnosis, to guide preventive interventions, to characterize the functional and prognostic profile of each patient and to plan effective non-pharmacological interventions. Interestingly, it has been found that at the early stages of Parkinson's Disease (Hoehn and Yahr scores - indicating the stage of PD disease- = 1), reactive but not proactive inhibition is impaired (Di Caprio et al., 2020). By contrast, when the disease become more severe (Hoehn and Yahr scores = 2-2.5), the impairment in reactive inhibition is stronger, and impairments of proactive inhibition appear (Mirabella et al., 2017).

Secondly, it is still unknown whether or not the behavioral performance at the emotional SST differs or not across psychiatric pathologies. In other words, it should be clarified whether the SST performance could be considered a transdiagnostic signature of psychiatric illness or whether the SST performance is specific for each psychiatric diagnosis (affecting peculiar components of the motor control), thus having the potential to become a behavioral biomarker.

All in all, data concerning neuropsychiatric patients data are highly suggestive of the fact that the investigation of how emotion and action inhibition processing interface, might open a key new window upon the complexity of their behavioral phenotype, , while at the same time offering some new anchors for innovative therapeutic interventions. Future research will, however, need to i) invest in designing standardized protocols, stimuli and procedure, as well as normative data, ii) understand whether the impact of emotions on action inhibition is also present in the earliest stages of psychiatric disorders; iii) understand the specific SST effect in each psychiatric pathology, in order to be able to translate this knowledge into a set of tools with novel clinical relevance.

Conflict of Interest Statement

Declarations of interest: none.

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Authors (year)	Participants (N)	Prime	Go signals	Stop signal	Go Task	Trials (N)	Main findings on inhibitory control
Verbruggen & De Houwer (2007)	Experiment 1 (23)	Negative, positive and neutral pictures	# and @	Auditory tone	Go signal discrimination	480	Longer SSRT for emotional trials
	Experiment 2 (22)	High-low arousal negative and positive pictures				640	Longer SSRT for high arousal pictures
Sagaspe et al. (2011)	(14)	-	Fearful and neutral faces	Red frame	Gender discrimination	400	No difference in SSRT
Herbert & Sutterlin (2011)	(31)	-	Unpleasant, pleasant and neutral nouns	Auditory tone	Responding to the word	450	Longer SSRT for emotional nouns
Krypotos et al. (2011)	(54)	Negative and neutral pictures	Arrows	Auditory tone	Arrow direction discrimination	320	Longer SSRT for negative pictures
Pessoa et al. (2012)	Experiment 2 (20)	-	Circle and square	Fear conditioned (CS+) and neutral tones (CS-)	Geometrical shape discrimination	500	Longer SSRT for the CS+ condition
You et al. (2012)	(28)	Erotic and neutral pictures	Arrows	Rhombus	Arrow direction discrimination	768	Longer SSRT for erotic images in men
		Pain and no-pain clips				640	Longer SSRT in the pain condition in men
Kalanthroff et al. (2013)	(22)	Negative and neutral pictures	# and @	Auditory tone	Go signal discrimination	480	Longer SSRT for negative trials

Rebetez et al. (2015)	(85)	-	Angry, happy and neutral faces	Auditory tone	Gender discrimination	384	Longer SSRT for negative trials
You et al. (2015)	Webcam-on group (26) Webcam-off group (16)	Erotic and neutral pictures	Arrows	Red dot	Arrow direction discrimination	768	Longer SSRT for erotic pictures in the webcam-off group
Song et al. (2016)	Early-stage love (23) Longer period love (20) Single group (40)	-	Sad and neutral faces	Red "x"	Emotion discrimination	480	Longer SSRT in sad trials Shorter SSRT for sad stimuli in the love group
Patterson et al. (2016)	Experiment 1 (18)	Negative and neutral pictures	Arrows	Auditory tone	Arrow direction discrimination	432	No difference in SSRT
	Experiment 2 (52)	Negative and neutral pictures (reappraisal condition)				648	Longer SSRT in the negative condition
Ding et al. (2020)	Female (22)	-	Sad and neutral faces	Red "x" mark	Emotion discrimination	480	Longer SSRT in the sad condition
Williams et al. (2020)	Experiment 1 younger adults (40) older adults (41)	-	Circle and square	Fearful, happy and neutral faces	Geometrical shape discrimination	900	Longer SSRT for older adults
	Experiment 2 younger adults (40) older adults (39)	-	Circle and square plus "emotional and neutral go-face" trials	Fearful, happy, and neutral faces plus stopping response only for one gender	Geometrical shape discrimination plus gender discrimination	900	No difference in SSRT

Table 1. SST studies in which emotional stimuli interfere with response inhibition in healthy participants.

Authors (year)	Participants (N)	Go signals	Stop signals	Go Task	Trials (N)	Main findings on inhibitory control
Pessoa et al. (2012)	Experiment 1 (32)	Circle and square	Fearful, happy and neutral faces	Geometrical shape discrimination	900	Shorter SSRT for emotional conditions
Senderecka (2016)	(33)	Arrows	Negative and neutral pictures	Arrow direction discrimination	400	Shorter SSRT for the negative condition
Senderecka (2018)	(32)	Arrows	Negative and neutral tones	Arrow direction discrimination	400	Shorter SSRT in the negative condition
Nayak et al. (2019)	(17)	Disgusted, happy and neutral faces	Red frame	Emotion discrimination	672	Shorter SSRT for happy faces
Choi & Cho (2020)	(33)	Circle and square	Red shapes	Geometrical shape discrimination under threat and no-threat conditions	384	Shorter SSRT in threat condition
Williams et al. (2020)	Experiment 3 younger adults (42) older adults (40)	Circle and square plus "emotional and neutral go-face" trials	Fear, happy and neutral faces plus stopping response only for one emotion	Geometrical shape discrimination plus emotion discrimination	900	Shorter SSRT for happy faces in older adults Longer SSRT for fear faces in younger adults

Table 2. SST studies in which emotional stimuli facilitate response inhibition in healthy participants.

Authors (year)	Participants (N)	Prime	Go signals	Stop signals	Go Task	Trials (N)	Main findings on inhibitory control
Lau et al. (2007)	Depressed patients (38) Non-depressed anxious individuals (26) Healthy controls (31)	-	Negative, positive and neutral adjectives; Non-words	Auditory tone	Words discrimination	576	Longer SSRT for non-words
Houshmand et al. (2010)	Bipolar disorder patients (34) Healthy siblings (22) Healthy controls (33)	Intense sadness and relaxed mood state	Negative and positive words	Auditory tone	Words discrimination	900	Longer SSRT for bipolar patients Longer SSRT for negative words Longer SSRT for bipolar patients under sadness context
Aker et al. (2014)	Depressed female patients (85) Healthy controls (62)	Angry and neutral faces	Arrows	Auditory tone	Arrow direction discrimination	160	No differences in SSRT
Allen & Hooley (2015)	Self-injuring individuals (33) Healthy controls (31)	-	Negative, self-harm, positive and neutral images	Auditory tone	Valence discrimination	Not reported	No differences in SSRT
Drentl & Habel (2017)	Schizophrenic patients (27) Healthy controls (27)	-	Angry and neutral faces within a white frame	Yellow frame	Respond to the white frame	400	Shorter SSRT for angry faces
Camfield et al. (2018)	Depressed patients (14) Healthy controls (21)	-	Negative, positive and neutral images in colored frames	Auditory tone	Color discrimination	720	No differences in SSRT

You et al. (2020)	Suicide attempters (41) Suicide ideators (38) Healthy controls (43)	-	Angry, sad and happy faces	Auditory tone	Emotion discrimination	800	Shorter SSRT for happy faces in healthy controls
Legrand & Price (2020)	Individuals with substance use disorder (72), divided by levels of depression and anxiety (low and high)	-	Angry, happy and neutral faces	Auditory tone	Gender discrimination	264	Longer SSRT for negative faces Longer SSRT in participants with high levels of depression Longer SSRT for emotional faces in participants with low level of depression and anxiety
Zheng et al. (2020)	Schizophrenic patients (36) Healthy control (36)	-	Curly and straight frames	Negative, positive and neutral images	Shape discrimination	648	Longer SSRT in schizophrenic patients

Table 3. SST studies with emotional stimuli in psychiatric population.