Differential relationships of childhood trauma and violent behaviour in adolescents with cognitive-emotional deficits

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Abstract

Exposure to adverse childhood experiences (ACEs) in the early stages of development has been correlated with the likelihood for externalizing behavior later in life such as getting involved in violent behavior. Converging neurobiological studies show that ACEs affect multiple densely interconnected neurobiological systems and disrupt the development of executive functions (EFs), especially the ability to inhibit inappropriate affects and actions, potentially modulating factors in the relationship between ACEs and violent behaviour. This study first sought to assess how EFs under non-emotional (cool) and emotional (hot) situations (i.e. emotion regulation) are related with high-exposure to ACEs, and whether any such relationships would be aggravated by acute stress. To achieve this goal, a new measure for hot inhibition, the facial expression Stroop task, and the use of *OpenFace*, a frame-by-frame machine classifier to analyse participant facial expression responses, was explored. Results showed consistent congruency effects as has been shown in other methods. Second, a two-experiment study involving Kenyan high school students was conducted to assess cool and hot EFs in a non-stress condition and in a social stress condition. Experiment 1 assessed neutral and emotional inhibition, working memory, and fluid intelligence alongside the ACE, violent behavior and demographics questionnaires. The study showed that reduced performance in both non-emotional and emotional inhibition (larger congruency effects) are positively correlated to ACE, while violent behavior was only related to deficient emotional inhibition. In a second experiment that implemented all the measures of Experiment 1, first without stress and then after a stress condition, results of experiment 1 were replicable before stress, and even after stress, the relationship between ACE to non-emotional inhibition and emotion regulation was not significantly affected. However, stress seemed to significantly affect the performance of the emotional inhibition task among participants who reported a higher involvement in violent behaviour. These findings show that violent behavior among victims of childhood trauma might be associated more with deficits in hot EFs than it is with deficits in cool EFs, especially more so under conditions of stress. Altogether, this study first shows the usefulness of OpenFace, a low cost yet effective tool to study facial behaviour in emotion regulation. Second, it opens perspectives towards more targeted research on, and interventions for ACEs, and third, it involves adolescents, a little researched age group, yet a sensitive period of EFs development.

Zusammenfassung

Negative Kindheitserfahrungen (Adverse Childhood Experiences, ACEs) in den frühen Entwicklungsphasen gehen mit der Wahrscheinlichkeit von externalisierendem Verhalten im späteren Leben einher, wie z. B. die Beteiligung an gewalttätigem Verhalten. Konvergierende neurobiologische Studien zeigen, dass ACEs mehrere dicht miteinander verknüpfte Hirnsysteme beeinflussen und die Entwicklung von Exekutivfunktionen stören, insbesondere die Fähigkeit, unangemessene Affekte und Handlungen zu unterdrücken. In der vorliegenden Arbeit wurde zunächst untersucht, wie Exekutivfunktionen in nicht-emotionalen (kühlen) und emotionalen (heißen) Situationen (d. h. Emotionsregulation) mit einer hohen Exposition gegenüber ACEs zusammenhängen und ob solche Beziehungen durch akuten Stress verstärkt werden. Hierfür wurde ein neues Maß für „heiße" Hemmung, die Gesichtsausdruck-Stroop-Aufgabe verwendet, sowie *OpenFace*, ein maschineller Klassifikator zur Frame-by-Frame-Analyse der Gesichtsausdrucksreaktionen der Teilnehmer. Die Ergebnisse zeigten konsistente Kongruenzeffekte, wie sie auch mit anderen Methoden nachgewiesen wurden. Darüber hinaus wurde eine weitere Studie mit zwei Experimenten an kenianischen schulpflichtigen Jugendlichen im Alter von 15-18 Jahren durchgeführt, um kühle und heiße Exekutivfunktionen in einer Nicht-Stress-Bedingung und in einer sozialen Stress-Bedingung zu testen. In Experiment 1 wurden die neutrale und emotionale Hemmung, das Arbeitsgedächtnis und die fluide Intelligenz zusammen mit den Fragebögen zu ACE, gewalttätigem Verhalten und demographischen Daten untersucht. Die Studie zeigte, dass eine verminderte Leistung sowohl bei der nicht-emotionalen als auch bei der emotionalen Hemmung (größere Kongruenzeffekte) positiv mit ACE korreliert, während gewalttätiges Verhalten nur mit mangelhafter emotionaler Hemmung zusammenhing. In einem zweiten Experiment, das mit den gleichen Maßen wie Experiment 1 durchgeführt wurde – zunächst ohne Stress und dann nach einer Stressbedingung – waren die Ergebnisse von Experiment 1 vor Stress reproduzierbar, und auch nach Stress war die Beziehung zwischen ACE und nicht-emotionaler Hemmung und Emotionsregulation nicht signifikant beeinflusst. Allerdings schien sich Stress signifikant auf die Leistung in der emotionalen Hemmungsaufgabe bei den Teilnehmern auszuwirken, die eine höhere Beteiligung an gewalttätigem Verhalten angaben. Diese Ergebnisse zeigen, dass gewalttätiges Verhalten bei Opfern von Kindheitstraumata eher mit Defiziten in heißen Exekutivfunktionen als mit Defiziten in kühlen Exekutivfunktionen verbunden sein könnte, insbesondere unter Stressbedingungen. Insgesamt zeigt diese Studie erstens die Nützlichkeit von OpenFace, einem kostengünstigen und dennoch effektiven Instrument zur Untersuchung des mimischen Verhaltens bei der Emotionsregulation. Zweitens eröffnet sie Perspektiven für eine gezieltere Erforschung von und Interventionen bei ACEs. Drittens bezieht sie Jugendliche ein, eine wenig erforschte Altersgruppe, die sich in einer sensiblen Phase der Entwicklung von Exekutivfunktionen befinden.

Synopsis

1 Introduction

Favorable childhood conditions offer a conducive milieu for the development of the brain from executing simple physiological reflexes, to more complex regulatory functions such as appetite, large and fine motor movements, emotion regulation, attachment, and in teenage, self-image and socialization (Perry, 2000a). That however, is not always the case. Due to children's high dependency on parents and caregivers, childhood has been shown to represent a highly risky period for exposure to potentially traumatic events such as physical and emotional abuse, made worse by children's limited coping skills (Lieberman & Van Horn, 2009). To describe such events, the term *adverse childhood experiences (ACEs)* was used in the Philadelphia seminal 'CDC-Kaiser Permanente' Study (Felitti et al., 1998) to refer to potentially traumatic events in the years prior to the age of 18, events that involve some form of abuse (physical, emotional, sexual), neglect (emotional or physical), and family disruption marked by household incidences such as witnessing one's mother being treated violently, parental separation or divorce, substance abuse, mental illness, and/or incarceration of a family member. These experiences are a common occurrence. According to the center for disease control and prevention (CDC, 2021), one in every six adults in the USA have experienced four or more types of ACEs, while of the top ten causes of death, five were associated with ACEs. An even more interesting finding by CDC (2021) is that the number of adults suffering from depression can be reduced by as much as 44% by preventing ACEs. In Germany, the occurrence of four or more ACEs was found to be 8.9% (Witt, 2019). A study by Craig and colleagues (2022) found the high-exposure to ACEs (≥4) in south Africa to be 23.6%. In Kenya, according to the violence against children survey (VACS, 2010), 73% of males (against 66% of females) reported having experienced physical violence, the most common form of childhood traumatic events in Kenya among boys. The number of ACEs one experiences have been shown to represent a measure of cumulated childhood stress (Anda et al., 2006). Specifically, ACE scores ≥4 have been shown to be the critical count at which ACEs begin to be positively associated with health and behavioural or learning problems (e.g., Burke et al., 2011; Chang et al., 2019; Hughes et al., 2017).

In the ACE seminal study, Felitti et al. (1998) used a pyramidal model (see Figure 1) to represent the impact of childhood trauma across lifespan. According to this model, exposure to traumatic events in childhood creates a vulnerability to impairments in social, emotional and cognitive abilities, which may then precipitate into adoption of maladaptive (health-risk) behaviours, disease, disability, social problems, and may lead to early death. Such effects constitute a public health issue, affecting not only the victim's health and wellbeing at the time of the ACEs occurrence, but also, their impact has been shown to be sustained into adulthood (CDC, 2021). Specifically, childhood adversity has been associated with mental health problems, alcohol and drug abuse, risky sexual behaviours, obesity, cardiovascular diseases, diabetes, cancer and poor outcomes across lifespan, in addition to their associated social and economic impact (Exley et al., 2015; Felitti et al., 1998; Liu et al., 2013). Kerker and colleagues (2015) found poor social development among children between ages 3-5 exposed to ACE, plus a 32% increased chance of a problem score on the child behaviour checklist, against every additional ACE score. Examining how ACE correlated with behaviour problems at age 9, Hunt et al. (2017) found that ACE scores equal to or greater than three were more strongly associated with externalising behaviours than with internalising behaviors. Among adolescents, ACEs have been associated with drug use and abuse, attempted suicide, poor physical and emotional health, and perpetration of violence (e.g., bullying, physical fighting, delinquency, carrying a weapon on school property) as well as violence towards self (suicidal ideation and attempt, and self-mutilation), with increased risk of committing such violent acts for each additional ACE (Duke et al., 2010). The model by Felitti et al. (1998) on ACEs and their consequences (Figure 1) placed social, emotional, and cognitive impairment immediately after ACEs, with problematic behavioural and health outcomes being the consequences that seem to follow such impairments. Two things are important to note here. First, it seems that social, emotional, and cognitive abilities are the immediate consequences of early childhood trauma (as indicated later by Anda et. al., 2006; DeBellis et al., 1999), and second, after the impairments in social, emotional, and cognitive abilities, poor behavioral, social and health outcomes seem to follow. Whereas the causes of maladaptive behaviour such as violence have been said to be multifactorial, that is; economic, social, cultural, family background, mass media, migration, and exclusion (Jones, 2014; Stasevic et al., 2005), the ACE model informs the current research in that the occurrence of ACEs seem to set in motion cognitive and emotional processes which may then form the basis for other outcomes. The current study therefore sought to understand ACEs and their possible association with externalising behaviour (violence in particular) from a cognitive and emotional processes perspective, processes that are part of executive functions (EFs).

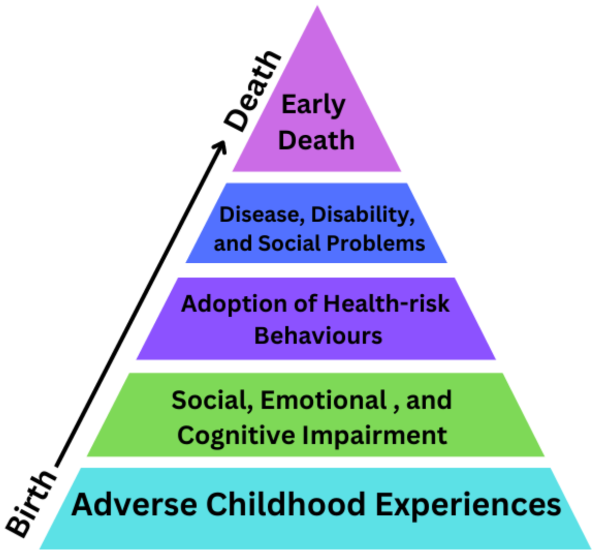

Figure 1 A conceptual framework of how ACEs affect development: Adapted from Felitti et al., 1998

1.1 Executive Functions

1.1.1 The Major Domains of Executive Functions

Traditionally, the idea of EFs was viewed as the distinction of automatic versus controlled forms of information processing, in the context of which, EFs referred to processes that demand deliberate, online exertion of control (Shiffrin & Schneider, 1977). More recent definitions refer to EFs as those processes that facilitate concentration and conscious attention at times when relying on autopilot would be risky, insufficient, or impossible (Diamond, 2013). Whereas other works have attempted to classify EFs based on the task processes they are involved in, such as (i) task-setting and problem-solving, (ii) response inhibition, (iii) task switching, and (iv) multitasking (Ward, 2020), there is a general consensus on three core EFs: inhibitory control, working memory, and cognitive flexibility (Miyake et al., 2000). Inhibitory Control is associated with the self-regulation mechanisms involved in hindering prepotent impulses and routine responses to a given stimulus or situation (Miyake et. al. 2000). According to Miyake and Friedman (2012), inhibitory control involves the ability to suppress a previously reinforced motor response (prepotent response inhibition), and the ability to resist or slow down irrelevant distractor information so as to carry out an appropriate response (interference control). Similarly, Shields and colleagues (2016) categorises dimensions of inhibitory control processes into response inhibition (e.g. as assessed by the Go/No-Go task), and cognitive inhibition (e.g. as assessed by the Stroop task). A comprehensive review of studies involving inhibitory control measures across these dimensions found no evidence that the two constructs are differentially related to measures of inhibitory control, showing that measures such as the go/no go task or Stroop task are valid measures of inhibitory control despite tapping into different dimensions of it (van der Bij et al., 2020). Working memory is related to active representation of goals, executive attention towards goal-relevant information and away from distracting stimuli, guarding goals and value sets from interference, suppression of contemplative thought, and regulation of unpleasant emotional states and longings (Hofmann et al., 2012). Functions that depend on working memory include reasoning, doing math in one's head, reordering things like a to do list, choosing alternative means of doing something, acquiring new perspectives relating to something (updating), converting guidelines into workable plans, creativity, breaking collective things into their component elements, and in decision making (Diamond, 2013). Cognitive flexibility (task switching) is linked to self-regulation aspects of switching between different ways of attaining the same results/goals or switching between multiple targets (Diamond, 2013). Cognitive flexibility engages inhibitory control in that actions and goals previously in play need to be inhibited in order for new responses to be adapted to a new set of conditions (Davidson et al., 2006). According to Miller and Cohen (2001), the ability to deliberately choose appropriate thoughts, emotions, and behaviours informed by the immediate demands of a given situation and social context, while suppressing improper habitual reactions, is the hallmark of efficient EFs. In comparison with the constructs of working memory and cognitive flexibility, inhibitory control has been shown to highly correlate with unitary EF, and seems to embody the purest domain of EFs (Miyake & Friedman, 2012).

It has been shown that, whereas the entire brain functions to link sensory inputs to their respective motor outputs, the PFC is uniquely situated to direct complex EFs (both cognitive and emotional) leading to adaptive behaviour by integrating highly processed information from sensory association areas into current contexts and priorities (Stern et al., 2015). It is thus conceptualised as the recipient of sensory, visceral and emotional information, which it then processes to generate complex cognitions, as well as flexible goal-oriented decisions, social interactions, and interpretations. Specifically, PFC and its related regions play a key role in social, emotional and motivational aspects of behaviour with functions of planning, task switching, working memory, problem-solving, goal-driven attention and novelty seeking attributed to the dorso-lateral PFC, while monitoring, response selection and inhibition served by the ventro-lateral PFC. Emotion regulation, self-knowledge, motivation, and updating goal directed behaviour are served by the medial prefrontal cortex, while the orbitofrontal cortex has been shown to play a key role in personality, inhibition, emotional and social reasoning (Jones & Graff-Radford, 2021). Neuroimaging findings have proposed several principles in which EFs are organised. One such principle is in relation to hemispheric differences of EF neural substrates, according to which, the separate roles of the left and right hemispheres are considered, with the left lateral prefrontal cortex seen as dedicated to functions related to task-setting, while right lateral prefrontal cortex is considered as dedicated to functions related to monitoring performance (Stuss & Alexander, 2000). Another way of organizing EFs has also been proposed, and considers the degree to which a function relates to emotion, reward, and/or motivation (i.e., 'hot' EFs), or purely cognitive aspects (i.e., 'cool' EFs). For the purposes of the current work, this model is important in three respects; first, both emotion and cognition are considered, an important aspect since day-to-day life is full of emotional triggers, second, it represents cognitive functions in a spectrum-like manner, signifying that all aspects of EFs, depending on context, can be hot or cool, and third, it goes beyond PFC to consider a broader range of brain regions that are involved in EFs including cortical and subcortical areas of the brain (Salehinejad et al., 2021). Neuroimaging studies investigating the brain regions involved under the 'hot'-'cool' EFs model have shown that both emotional and non-emotional stimuli tap into similar regions, that is, dorsal anterior cingulate cortex (dACC), anterior insula, and lateral and medial PFC (e.g., Menon et al., 2010). Other findings have shown that tasks imbued with emotional conflict recruit specific neural regions, that is, amygdala, medial PFC, orbitofrontal cortex, and more rostral areas of the ACC, involved in salience and affect processing (e.g., Xu et al., 2016). Lesion studies among adults have also shown the functional dissociation of the prefrontal cortex into orbital and dorsolateral prefrontal cortex, with damage to the orbitofrontal cortex affecting experience-based emotional representations, leading to deficiencies in making adaptive decisions that require careful evaluation of future reward and punishment (Bechara, 2004). With so many accounts on EFs, Table 1 represents a summary of what is currently known on the major domains and their related brain regions as discussed by Salehinejad and colleagues (2021).

Table 1

Major executive function domains and their related brain regions as per current knowledge (Salehinejad et al., 2021)

	Cool Executive Functions		**Hot Executive Functions**	
Major Domains	Attentional control, working memory, response inhibition, cognitive flexibility, problem solving, performance monitoring, error detection, multi-tasking, fluency.		Emotion regulation, reward processing, affective decision, risky decision making, delay discounting, social cognition, self-referential, and any cool EF domain with emotional or motivational features	
Brain Regions	**Cortical**	**Subcortical**	**Cortical**	**Subcortical**
	Dorsolateral prefrontal cortex	hippocampus	Medial prefrontal cortex	Amygdala
	Lateral prefrontal cortex	Basal ganglia	Ventrolateral cortex	Insula
	Anterior cingulate cortex		Orbitofrontal cortex	Limbic system
	Inferior frontal cortex			Striatum

Real-world conditions differ in ways that are motivationally and emotionally significant (i.e., 'hot' factors), yet, the study of executive functioning has traditionally explored specific cognitive abilities that aid goal-directed behaviour in non-emotional ('cool') settings with little regard for context (Welsh & Peterson, 2014). Stressful life events such as losing a job, followed by financial difficulties and the emotional rollercoaster of job hunting, may result in behavioural outcomes different from contexts that do not involve such stress. Emotionally valenced contexts or life events call for emotion regulation abilities, a concept closely related to inhibition and refers to 'the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions' (Thompson, 1994, p. 27). Emotion regulation is called for when emotional contexts automatically draw attention, interfering with other processes (Tottenham & Casey, 2011) and causing cognitive conflict (Song et al., 2017). Such cognitive conflicts have been demonstrated in the temporal costs in the emotional Stroop task, in which emotional stimuli interfere with response time (RT) in a manner irrelevant to the color-naming task (Chiew & Braver, 2010). For instance, when responding to the print color of neutral words (e.g., 'and') or emotional words (e.g., 'death'), participants record RTs that are longer for emotional words, compared to neutral words (Williams et al., 1996).

1.1.2 Measuring Executive Functions

Going by the three core EFs (Miyake et al., 2000), among other measures, assessing working memory has been done using tasks such as the *n-back* (Kirchner, 1958) and the *complex span paradigm* (Conway et al., 2005). Inhibitory control has been assessed using the *standard colour-word Stroop task* (Stroop, 1935) and the *go/no-go task* (Donders, 1969), while cognitive flexibility has been measured using tasks such as the *Wisconsin Card Sorting Test (WCST)* (Grant & Berg, 1948). Measuring EFs under 'cool' and 'hot' contexts has also been tried in some studies (e.g., Casey et al., 2011). Table 2 summarises some of the measures that have been used.

Table 2

Behavioural tasks used for measuring executive function under cool and hot domains as discussed by Salehinejad et al., 2021

	Cool Executive Functions		**Hot Executive Functions**	
Major Tasks	n-back/digit span	Stroop	Emotion regulation task	Iowa gambling task
	Go/No-Go / Stop signal	Continuous performance tasks	Emotion tracking task	Monetary decision
	Tower of London	Task-switching	Reward-based tasks	Self-attribution task
	Attention shifting	Conflict tasks (e.g., Fanker task, Simon task)	Theory of mind	Any cool EF task with emotional or motivational features

Just as EFs can be perceived in a spectrum-like manner, signifying that all aspects of EFs, depending on context, can be 'hot' or 'cool,' 'cool' EF tasks can be imbued with emotional or motivational features to make them 'hot' EF measures. For instance, in the classical colour-word Stroop task, when responding to the print color of a neutral word (e.g., 'and') or emotional words (e.g., 'death'), participants record RTs that are longer for emotional compared to neutral words (Williams et al., 1996). Since in this emotional Stroop task only one part of the stimulus is affective, it may lack semantic emotional conflict between the non-emotional target (e.g., font-colour) and the distractor (e.g., emotional word). Tasks that embody such a quality where the target and distractor are affective afford the researcher the possibility to manipulate attention towards a specific emotional target, and away from an equally emotional distractor information, resulting in semantic emotional conflict, a desirable quality for 'hot' EF tasks. Such tasks would include for instance, the use of Facial expressions as an emotional 'hot' task. For example, Casey and colleagues (2011) utilised happy and fearful facial expressions as stimuli for the 'hot' version of the go/no-go task. They showed that participants with low scores on self-control and delayed gratification measures performed poorly when instructed to suppress a response to a happy face, compared to when the faces were frowning and neutral. This shows the significant role that 'hot' cues play in a person's ability for example for delayed gratification, a construct that is dependent on inhibitory control (Eigsti et al., 2006). A study by Loeffler and colleagues (2019) among 26 patients with a history of major depressive order (compared to 26 healthy controls) assessed participant's attention control (ability to attend to the required emotional stimuli) via their performance in an emotional face-word Stroop task, in which emotional words, "Trauer" (sadness) or "Freude" (happiness) were printed above the nose at the centre of a face whose expression was either congruent or incongruent with the word label. Through a button press, participants were required to identify as accurately and as fast as possible, the emotion of a given facial expression, while ignoring the word label. Participants performed the face-word Stroop task together with a cognitive emotion regulation task as they underwent fMRI. The cognitive emotion regulation task tested participant's ability to change their emotional experience by changing how they interpreted a given situation. For instance, to enhance personal relevance, participants were instructed to imagine that the face in the stimuli was that of a close relative. To increase relevance, participants were asked to imagine that they were responsible for the person's happiness or sadness as expressed in the face stimuli, or decrease relevance by imagining that they were not responsible for the person's emotional state. Speed and accuracy of the button press responses to facial expressions required participants to suppress emotional distractors (emotional words). Results showed that participants who were less distracted by the word ‘sadness’ on happy faces were also better at the emotion regulation task. Specifically, in the face-word Stroop task, patients displayed higher attentional disengagement from positive stimuli relative to negative stimuli, an indication that attention control and affect regulation capabilities may be linked at both the behavioural and neural level. This points in the direction the face-word Stroop may indeed be used as a measure of emotion regulation, a paradigm that calls for the ability to overcome the distractor interference and resolve the resulting cognitive conflict, a process that has been connected to the frontal cortex, as well as brain regions connected to affect processing (Loeffler et al., 2019; Xu et al., 2016).

Recent studies have extended the Stroop task into the domain of facial expressions in which participants respond with a smile or frown to words pertaining to emotions (e.g., ‘HAPPY’ or ‘ANGRY’) written over emotional faces (e.g., happy or angry faces). (e.g., Recio et al., 2022). To investigate the control over facial expressions, a Stroop-like paradigm was used in which background distractor stimuli were adult faces showing expressions of joy and anger, and infant faces showing expressions of happiness and distress. In this paradigm, participants were required to respond by producing the facial expressions indicated by written commands, ‘*Freude' for happiness and 'Ärger' for anger*, superimposed on the center of facial stimuli. The stimuli were then presented in a way that target responses were either congruent (e.g., *anger* written over an angry face) or incongruent (e.g., *happiness* written over an angry face) with the distractor face image. Participant responses were recorded as videos via a camera, and the videos were coded frame-by-frame for analysis using the *OpenFace* software (Baltrusaitis et al., 2018), a machine classifier. This study confirmed an overall congruency effect with RTs being slower for incongruent relative to congruent stimulus conditions. Longer RTs have been accounted for by cognitive conflicts getting in the way of behaviour regulation in emotional contexts, and resolving such cognitive conflict requires time to deploy attentional resources, like amplifying task-relevant stimuli while ignoring irrelevant information (Egner & Hirsch, 2005). Facial mimicry, the spontaneous and congruent activation of facial expression muscles upon observing a given emotional facial expression (Dimberg & Petterson, 2000), and stimulus response-compatibility have been used to explain the kind of interference effects registered under incongruent facial expressions (Otte et al., 2011a). Performance in RTs in compatible trials is faster due to facilitation effects as the reflexive responses in mimicry involve little or no cognitive processing, while RTs in incompatible trials may be slower due to inhibition effects as more cognitive processes are called for to resolve cognitive conflicts occasioned by the reflexive mimicry of the distractor face. With studies (e.g., Koole, 2009) showing that regulating bodily emotional responses such as facial expressions is the goal of emotion regulation strategies, it is possible to conclude that, unlike the colour-word Stroop task, the facial expression Stroop task used in this study is directly related to inhibition of an emotional response (i.e. emotional facial expression), and therefore a measure of emotion regulation.

With the study by Recio and colleagues (2022) being the only study known to have used video coding with a machine classifier to show congruency effects for facial expression onsets in this facial expression Stroop task, it was important to first corroborate these findings before implementing the facial expression Stroop task in our study. The first part of my research (see section 2.1) involved exploring this measure of emotional facial expression Stroop task.

Everyday life calls for face-to-face exchanges in which facial expressions are channeled to pass messages, or controlled and/or adapted to suit a given situation, facilitate communication, social coordination and interaction, thus enabling individuals to relate and participate in collective action. Guiding our actions, especially under conflict situations, call for the integration of emotion regulation and cognitive control (Recio et al., 2022).

1.1.3 Executive Functions in Everyday Life

Every day, we encounter situations that require us to make decisions, solve problems, handle novel unanticipated challenges, plan and co-ordinate actions, change plans, and choose one action from many alternatives while overriding strong external and inner allures. Real-world situations further differ in ways that are motivationally and emotionally significant, thus, EFs are necessary in everyday situations that demands one to overcome the impulse to choose an overly alluring response over the need to intentionally focus on meeting the demands of a given context. Efficient executive control therefore has crucial implications for everyday life. Inhibitory control for instance enables one to self-regulate, a broad domain that involves physical, cognitive, emotional, attentional, and behavioural regulatory processes in support of adaptive functioning and goal-directed behaviour (Peterson et al., 2016). Situations such as choosing between finalising an important assignment over the impulse to binge on Netflix, picking a fruit over dessert at the dinner table, or choosing emotional restraint in resolving interpersonal conflicts over yelling or fighting demand that one reigns over the temptation to respond impulsively, and instead, be intentional. Deficits in EFs affects almost every aspect of life, and have been associated with heightened possibility of depression (Taylor-Tavares et al., 2007), attention deficit hyperactivity disorder (ADHD; Diamond, 2005), conduct disorder (Fairchild et al., 2009), obesity (Crescioni et al., 2011), school readiness and academic achievement (Jacobson et al., 2011), failure to find and keep a job (Bailey 2007), marital discord (Eakin et al., 2004), and generally, low quality of life (Brown & Landgraf, 2010). Studies have also suggested an inverse relationship between executive functions and externalizing behaviour. According to a review by Brower and Price (2001), some studies have suggested a link between frontal lobe dysfunction and increased violent and antisocial tendencies, with increased aggression being positively associated with focal orbitofrontal injury. Whereas this review found no distinctive relationship between frontal network dysfunction and violence, it showed that focal prefrontal damage was highly associated with the impulsive subtype of aggressive behaviour such as explosive reaction to situations with the possibility of harming others. The aforementioned literature however considered clinical groups such as participants with neurological ailments (e.g., Blair et al., 2006). There is a dearth of literature exploring how a normal population may differ in its propensity towards violence. Bearing in mind the aspects of literature showing that frontal network dysfunction is correlated with violence (e.g., Browser & Price, 2001), and literature showing that stressful childhood events may cause impairments in EFs (Mothes et. al., 2015), my study sought to explore possible connection between ACEs, EFs deficits, and violent behaviour.

1.2 Effect of Adverse Childhood Experiences on Executive Functions and Its Manifestation in Violent Behaviour

As early as before the age of three, EFs begin to emerge, with a protracted development into early adulthood, before they decline as one ages, trajectories that have been linked to structural and functional changes in the prefrontal cortex (Sowell et al., 2001). Diamond (2013) suggested that different components of EFs develop at different rates across childhood and adolescence, and reach maturity at different ages. At the age of 3 to 4 years, cognitive flexibility emerges, and continues into more complex functioning from the age of 7 to 9 years, with adult-like level of functioning emerging at the age of 12 years. Other studies (e.g., Zelazo et al., 2014) have argued that cognitive flexibility continues to improve into young adulthood (20-29 years). WM and inhibition too continue to develop across childhood and adolescence, and in some instances into young adulthood (Ferguson et al., 2021). According to a study among 350 participants aged 10-86 years, Ferguson et al. (2021) found improved WM capacity across adolescence into adulthood with declines in WM and inhibitory control beginning between the ages of 30 to 40, with further declines into older age. Generally, Mothes and colleagues (2015) argue that EF development takes on a 3-stage trajectory. That is, - (i) by the age of 6 years; develop simple planning and visual search abilities; (ii) by the age of 10 years; develop the skills that aid in maintaining context, impulse control, and hypothesis testing; (iii) during adolescence, develop complex planning capabilities, motor sequencing skills, and verbal fluency abilities. When development of EFs during the transition to adolescence is looked at through the hot and cool domains, cool EFs have been shown to occur earlier, while hot functions occur later and more gradually, a finding that may account for risky behaviour tendencies in adolescence (Prencipe et al., 2011). Converging evidence from neurobiology and epidemiology have indicated that exposure to traumatic events in the course of any of these stages may cause enduring brain dysfunction (Anda et. al., 2006). A Functional Magnetic Resonance Imaging (fMRI) study by De Bellis (2001) showed an overall smaller brain volume among children diagnosed with posttraumatic stress disorder (PTSD) as a result of maltreatment, compared to a control group of non-maltreated children. A more recent longitudinal prospective neuroimaging study (Luby et al., 2017) explored the possibility of neurobiological pathways that propel victims of early childhood trauma on a trajectory of mental and physical health problems. Luby et al. (2017) found that ACE adversely altered the volume of a subregion of the prefrontal cortex and the inferior frontal gyrus, which are positively associated with reduced emotional competence and a high risk of depression among adolescents.

The current study considered how the impact of ACEs on EFs may correlate with violent behaviour during adolescence, the age where more abstract and complex ways of thinking are consolidated, making it a specifically sensitive age for the expression of the effects of exposure to ACEs on EFs, expressions that mostly take the form of negative coping mechanisms (e.g., Jonson-Reid, et al., 2012) such as violent offending (Fox et al., 2015).

Several studies have found strong associations between externalising behavior and exposure to ACEs, with poor self-regulation as a developmental sequela of exposure to ACEs (e.g., Cristóbal-Narvaez et al., 2016; Hunt et al., 2017). For example, in a longitudinal study that followed 1575 children (667 in the control group) over a 20-year period after reporting childhood mistreatment, it was found that experiencing abuse or neglect increased the chances of being arrested as a youth by 53%, with exposure to childhood abuse and neglect being positively and significantly correlated with the likelihood of arrest for violence and adult criminality (Maxfield & Wisdom, 1996). Reavis and colleagues (2013) reported nearly four times more ACEs in a group of adult male criminal offenders than in a control group, while Fox and colleagues (2015) found that for every additional ACE experienced, participants' risk of becoming a serious, violent, and chronic (SVC) juvenile offender increased. Multiple ACEs have also been shown to represent risks such as violence for the next generation (Hughes et al., 2017). Additionally, Guedes and Mikton (2013) found that childhood mistreatment, and especially so, exposure to violence, abuse (physical or sexual) increased the victim's risk of being a victim or an aggressor of intimate partner violence (IPV). Whether considered cumulatively, categorically, or individually, it is apparent that ACEs are associated with violent tendencies. With such strong evidence in literature linking childhood trauma and violent behavior, the next question would be to consider the psychological links between ACE and violence in adolescence.

In a comprehensive systematic review of studies on inhibitory control among trauma-exposed youth, van der Bij and colleagues (2020) considered 33 studies, 12 of which measured different dimensions of inhibition. Their results showed that trauma-exposed youth had deficient inhibitory control, an important finding since deficient inhibitory control and violent behaviour have been positively correlated (Qiao et al., 2016).

Such correlations have however been even more pronounced under emotional contexts that under neutral contexts (Botdorf et al., 2017), with poor performance on inhibitory control under emotional contexts, but not neutral contexts, correlated to emotional problems among adolescents (Poon, 2018). Since EFs, shown to be negatively affected by ACEs, are central to everyday life which is commonly saturated with motivational and emotional cues, one may suggest that people can hold impulses in check under emotionally neutral (cool) conditions, but their emotion regulation, and by extension, self-regulation systems may be compromised under stressful contexts. The current study explored how stress affected EFs.

1.3 Stress and Executive Functions

Stress occurs when demands made on an organism exceed its regulatory capacity to meet them (Koolhas et al., 2011). Whereas individuals may differ in the way they deal with stressful scenarios, the biopsychosocial approach to this dynamic concept of stress has shown commonalities in that stress affects the emotional, physiological and cognitive state of an individual (Delahaij et al., 2011). When one encounters a stressful event, the hypothalamic-pituitary-adrenal (HPA)-axis releases corticosteroids (corticosterone in rodents, cortisol in humans) which bind to the mineralocorticoid receptor (MR) and the glucocorticoid receptor (GR), two receptors in the brain that regulate HPA-axis activity (Harris et al., 2013). On the one hand, these hormones ensure sufficient energy is available, and on the other, cortisol exerts a negative feedback to the HPA-axis to prevent an overshoot. A rapid HPA-axis activation after stress, and its effective termination when stress subsides is the hallmark of an efficient and adaptive stress response (McEwen, 2004). This is so because elongated HPA-activity as a result of chronic stress may exceed a person's allostatic load, leading to the development of somatic and psychiatric problems (Juster et al., 2010). A high density of stress hormone receptors (MR and GR) are situated in the prefrontal cortex, and its functioning is mostly affected by stressful conditions, as the executive control network which facilitates the usage of higher order cognitive processes are decreased as a result of the neurotransmitter receptor binding (Shields et al., 2016). Empirical findings have shown that stress affects EFs in a way as to allocate priority to processing information that is directly related to an ongoing stressor (Mather & Sutherland, 2011). Studies have however differed on which EFs are enhanced, and which are impaired. For example, Shields and colleagues

(2016), found that under stress, cognitive flexibility and working memory are impaired as cognitive resources are channelled from those functions to aid selective attention, enhancing the response inhibition dimension of inhibitory control processes, and reducing the cognitive inhibition dimension. Such findings have been confirmed by others (e.g., Eysenck et al., 2007) who have argued that under stress, selective attention may deteriorate, and so would inhibitory control. Furthermore, Vogel and colleagues (2016) have reasoned that stress shifts cognitive resources from top-down control processes to the more automatic bottom-up control processes, and since core EFs are considered top-down control processes, the implication is that stress impairs working memory, cognitive flexibility and cognitive inhibition.

In a study by Stawski et al. (2010), over 1202 adult participants (mean age, 57 years) were first assessed for fluid cognitive ability (FCA) using the Brief Test of Adult Cognition by Telephone (BTACT) battery which tests domains of working memory span, episodic verbal memory, reasoning, speed of processing, and executive function. BTACT subtests had shown significant correlations with standard neuropsychological tests as used in laboratory settings, with no significant difference with in-person administration. Three months later, participants enrolled for the National Study of Daily Experiences where, using the Daily Inventory of Stressful Events, filled a daily stressor diary by reporting their positive and negative affective states for eight consecutive days through an evening phone call. The study findings indicated that compared to those with lower cognitive capabilities, participants with higher levels of FCA, even when they experienced more stressful daily situations, recorded lower mood changes in response to stressful situations. This demonstrates that executive functions are crucial mechanisms in emotion regulation.

In a study by Starcke, Wiesen, Trotzke, and Brand (2016), healthy participants between the age of 20 to 67 years, and free of acute, chronic or psychological disease, were randomly assigned to a stress or control group. Stress was induced in the stress group using the Paced Auditory Serial Addition Test – a computerised version - (PASAT-C). The control group was instructed to relax for approximately the same duration it took the experimental group to perform the PASAT-C. Five EFs; inhibition, attention, planning, monitoring, and task management were measured. Except for monitoring, all the executive functions studied were performed significantly lower by the stress group compared to the control group

(Starcke et. al., 2016). To be able to handle stressful life events well demands effective and efficient cognitive control and emotion regulation abilities, functions that have been shown to be affected by early childhood trauma (Felitti et al., 1998; Mothes et. al., 2015). It was therefore of great interest to explore the impact of stress on EFs among victims of childhood adversity, shown to run the risk of affect processing and regulation (Panayiotou et al., 2021). According to Gunnar and Quevedo (2007) early life stress causes anomalous production of glucocorticoids by the adrenal glands leading to highly activated hypothalamus-pituitary-adrenal (HPA) axis, resulting in sustained, thus over production stress alleviating chemicals resulting in allostatic load (Fox et. al., 2015). High allostatic load has been associated with impaired brain development and maladaptive affect processing and regulation (Panayiotou et al., 2021). In order to test the impact of stress on victims of ACEs, we considered an ethical way to induce stress to the participants.

Biopsychological stress responses have been shown to be elicited robustly and reliably under circumstances where elements of social-evaluative threat and uncontrollability come together (Dickerson & Kemeny, 2004). In laboratory settings, bringing together the elements of uncontrollability and social-evaluative threat, have been shown to induce moderate stress, with cardiovascular and HPA axis response increasing up to 2-3-fold (Dickerson & Kemeny, 2004). This is backed by recent studies that have shown that engaging participants in public speaking and public mental arithmetic combines the necessary elements in laboratory settings to elicit reliable stress responses (e.g., Dawans et al., 2011). von Dawans and colleagues (2011) incorporated the conditions social-evaluative threat and uncontrollability in a task that involved public speaking and a mental arithmetic task before a team of evaluators and a camera in the Trier Social Stress Test (TSST), and demonstrated among multiple participants that the test significantly induces increased cortisol levels and heart rate, making it an effective, economical, ethical and novel stress induction protocol under controlled conditions. Considered a gold standard for exploring the effects of stress in humans (Allen et al., 2017), and with the preceding literature showing that stress affects EFs, the group format (TSST-G) of this stress induction protocol was utilised in the present study to test cognitive functioning under stress.

1.4 Aims and Outline of the Present Work

Adolescence has been referred to as the age of all gasoline, with no brakes and no steering wheel (Bell & McBride, 2010), alluding to diminished self-control and regulation as depicted by Casey and Caudle (2013). At a biopsychological level, it is a sensitive period for EF development (Borrani et al., 2015), marked by heightened sensitivity to emotional cues (Romeo, 2013), yet, according to a systematic review of recent empirical studies on cognitive abilities and EFs, Baggetta and Alexander (2016) found that only 8% of 711 articles included focused on adolescents compare to children (24), adults (32), and older adults (20). Even more, according to Poon (2018), there is a deficiency of data on how hot compared cool EFs progressively develop during adolescence. With a dearth of studies focusing EFs during adolescence, the overarching aim of the present study was to investigate the relationship between the severity of ACEs and EF, and how any EF deficits may be exacerbated by emotional contexts, stressful conditions, and how any such relations may correlate with violent behaviour among male adolescents. Specifically, we sought to (i) explore a new measure for hot inhibition (our facial expression Stroop task) using a machine classifier (the *OpenFace* video analysis software), (ii) explore the relationship(s) between ACE, hot and cool cognition, and violence, and (iii) explore the effects of stress on these relationships.

Measures of EFs were inhibitory control, WM, fluid intelligence, and emotional regulation. First, I tested the facial expression Stroop task to ensure plausible congruency effects with video outputs analysed by *OpenFace* software. Second, in a two-experiment study, I investigated the relationship between EFs and ACEs under neutral (cool) and emotional (hot) contexts, and their relationship to violent behaviour, and in a second experiment, I sought to replicate the findings of the first experiment, then assessed the effect of acute stress on those relationships, and how such effects may relate with violent behaviour. Two separate samples of Kenyan adolescents from the general population with varied experiences of violent behavior and childhood trauma were used for experiments 1 and 2.

In the first part of this research, the emotional facial expression Stroop task output analysis using a machine classifier was explored. Based on facial mimicry, the tendency of observers to spontaneously elicit the facial expressions of the observed (e.g., Dimberg & Petterson, 2000), we hypothesised that (1) for congruent conditions, RTs would be shorter than in the incongruent condition, while expression accuracy and mean AU activation might be higher due to possible facilitation effects of congruence, and (2), that under incongruent conditions, accuracy would be lower and RT would be shorter than in neutral and congruent conditions. It was also of interest to find out whether AUs that do not "belong" to a required target expression (e.g., anger-associated AUs might be activated during an incongruent smile) may be co-activated as a function of congruency, thus 'contaminating' the target responses, resulting in to 'mixed' facial expressions. In the second part, a two-experiment study looked first at how ACEs, EFs, and Violence are related. Informed by earlier findings which positively associated ACEs with reduced emotional competence (e.g., Luby et al., 2017) and risk of being a violent offender (e.g., Fox et al., 2015), this study hypothesized that; (1) differential relationships exist between inhibition in non-emotional and emotional contexts with childhood trauma and violent behavior, and (2), with stress having been shown to affect the emotional, physiological and cognitive state of an individual (Delahaij et al., 2011), a condition of induced social stress would aggravate the associations in (1).

This research is inspired by several factors. First, there is a dearth of research on cognitive and emotional abilities among adolescents, and more so, adolescent victims of childhood trauma, yet it is a sensitive period of EF development, marked by heightened sensitivity to emotional cues. Second, to the best of my knowledge, this is the first study to use a machine classifier to analyse video outputs of an emotional expression Stroop task in the context of emotion regulation and cognitive control research among victims of early childhood trauma. Third, most of the research on the cognitive mechanisms of ACE having been carried out among western, educated, industrialised, well-to-do and developed populations, the findings from this research with Kenyan participants will offer a source for cross-cultural comparisons.

2 Summary of the Present Studies

2.1 Effects of Social Context on Deliberate Facial Expressions: Evidence from a Stroop- like Task

A unique aspect of this research is how it combines 'hot' (i.e., emotional) tasks and 'cool' (i.e., emotionally neutral) tasks and a condition of stress among adolescent participants with different levels of childhood adversity. With findings such as those by Botdorf and colleagues (2017) showing that emotional Stroop tasks and not a cognitive task predicted risk-taking in a laboratory driving task, it was of interest to have a task that embodied emotional milieus. In this first part of the research, the use of the facial expression Stroop task was explored.

The first study involved 18 participants (11 females and 7 males, mean age: 26.12 years, *SD* = 5.6, range 21 - 39), with no history of neurological or mental disorder, and all reported normal or corrected-to-normal visual acuity who performed the facial expression Stroop task. Using pictures of adults and infants with positive, negative, neutral and scrambled face as background stimuli, and with the words *Freude* (Happy) and *Ärger* (Angry) superimposed on the faces at the saddle of the nose, participants were instructed to smile or frown as fast and accurately as possible in response to the word superimposed on the visual stimulus. The written commands and facial expressions were orthogonally combined to yield congruent (smile response plus happy face; frown response plus angry face), incongruent trials (smile response plus angry face; frown response plus happy face), neutral (smile or frown response plus neutral face), and scrambled trials (smile or frown response plus scrambled face). These responses targeted the activation of AU4 (*m. corrugator supercilii*/brow lowerer) for frowns and AU12 (*m. zygomaticus major*/lip corner puller) for smiles (Tian et al., 2005). As participants carried out this experiment, their responses were captured via a video recorder. The video recordings were then analysed frame-by-frame with *OpenFace* (version 2.0.2, Baltrusaitis et al., 2018). OpenFace is an open source tool with an algorithm that is trained on faces viewed from several perspectives, and has demonstrated high accuracy outcomes for tasks requiring facial action unit recognition, facial landmark detection, eye-gaze estimation, and head pose estimation. With the ability to analyse 17 AUs; their accuracy, RTs and activity, this machine classifier offers richer information at a cost less than using EEG and EMG, and this was important for the study summarised in section 2.2 since EEG and EMG were not available where the data would be collected from.

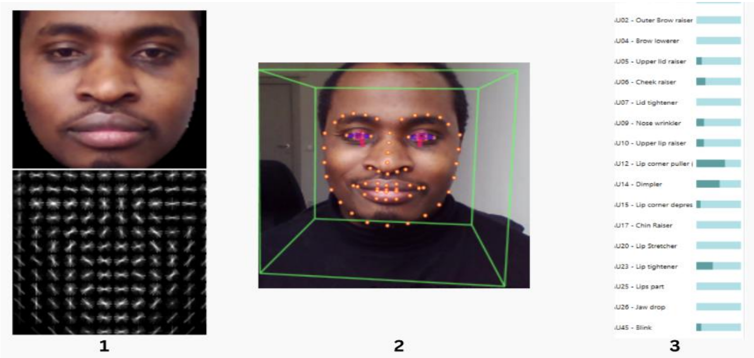

Figure 2 Key Algorithms in OpenFace showing (1) facial appearance (2) facial landmarks, eye gaze, head pose and (3) facial action units

The AU output values range from 0 to 5, with 0 indicating no activity, 1 indicating weak activity, while 5 indicates maximum activity of a given AU. *OpenFace* output text files were converted to .xlsx format in Microsoft Excel (v. 2016). Using timestamp information in the output, the data stream containing stimulus events was merged with the excel files from OpenFace output. Using a similar procedure as reported by Recio and Sommer (2018), the datasets containing stimulus event information were processed with MATLAB (R2016a, The Math Works, 2016). A correct response (hit) was defined as activity in the target AU channel that preceded any activity in the distractor AU channel and lasted for at least seven consecutive frames above threshold. RTs were only analysed for correct trials (hits), and the rest were classified as errors. Such definition ensured that measures were not from noise, or as a result of too fast guesses.

Whereas verifying this method for use as an emotional Stroop task in the study in section 2.2 was informed among other things by the unavailability of EEG and EMG where the data was collected from, the machine classifier provides several advantages. First, besides the targeted AU4 and AU12, it provides measures of activation for 17 AUs, making it possible to simultaneously measure more AUs and thus other responses such as fear, disgust, and surprise. Besides the RTs, outputs also provide the accuracy and intensity of responses, making its output richer. Second, compared to the other methods, the machine classifier provides a low cost yet effective measure, and third, the use of the machine classifier frees the facial expression muscles from the possible occlusion by electrodes used in other measures such as EMG.

As a nonverbal channel of communication, the face through its expression can reveal a person's affective and cognitive state such as how they feel, whether or not they are pleased with something, whether or not they want to engage with another or in an activity, or even their intentions (Baltrusaitis et al., 2018). Therefore, being able to analyse facial behaviour using *OpenFace* (or other machine classifiers) has the potential of revealing both cognitive and affective states.

In this part of the study, I examined how deliberate facial expressions of happiness and anger (smiles and frowns) prompted by written commands, are modulated by the congruency with the facial expression of background faces, assessing error rates, activity and response times (RTs). The most consistent findings were effects of congruency, especially so for RTs under conditions with adult background faces, with clear effects of facilitation due to congruence and inhibition due to incongruence. Such findings may be explained by facial mimicry (Dimberg & Petterson, 2000). Thus, congruent conditions are faster as they are favoured by mimicry, while incongruent conditions are slower since overcoming mimicry reflexes to elicit the desired, more reflective response, requires time to recruit and deploy cognitive processes to detect and resolve conflicts inherent in incongruent trials (Egner et al., 2008). Studies have also shown that mimicry is a multifactorial response with some levels of adaptability and flexibility moderated by personal, emotional, motivational, relational, and social characteristics of both the mimicker and the mimickee in a given context (Chartrand & Lakin, 2013; van Baaren et al., 2009). Thus, stimuli laden with emotional meaning (e.g., facial expressions) may engage cognitive and emotional regulation mechanisms to inform appropriate facial responses. According to Tottenham and colleagues (2011), affective stimuli tend to automatically attract attention, interfering with other processes, leading to cognitive conflict (Song et al., 2017). Such conflict calls for cognitive abilities such as attention bias and perception, thus weakening irrelevant information, and enhancing task-relevant information (Egner & Hirsch, 2005). This was achieved in the emotional Stroop task where affective stimuli interfered with other non-affective responses resulting in cognitive conflict.

In the other findings, that the quality (accuracy) of smiles, and not frowns, was shown to benefited from congruent conditions. This might be explained by the fact that naturally, people are socialised to be friendly, favoring smiles over frowns (Ekman and Friesen, 1969a), findings that are in tandem with later studies showing that smiles are more acceptable and bears no personal costs (Künecke et al., 2017). These explanations may also suffice for my findings that smiles were more accurate than frowns, although this came with a caveat of occlusion by EEG cap on the AU4 (*m. corrugator supercilii*/brow lowerer). Whereas smiles and frowns would be represented by AU12 and AU4 respectively, the machine classifier's ability to analyse over a range of 17AUs also and found that AU2, the outer brow raiser, (a different expression from a prototypical anger expression), elicited low activity when participants were required to frown at a frowning background face of an adult, and high activity when participants were required to frown at the background face of an infant in distress. This effect of stimulus age might be explained by infant's anatomical characteristics such as big eyes and a round face on a large head, referred by Lorenz (1943) as 'Kindchenschema', characteristics that induce motivation for caregiving behavior, especially among adults (Glocker et al., 2009). However, that may not always be the case as Korb et al. (2016) have shown that when oxytocin levels in the observers were increased, adult participants mimicked angry infant faces. Such variances may explain the activation of AU2, especially with studies showing the possibilities of 'miserable' or 'masking' smiles (Ekman, 1985) and simultaneous activation of happiness and sadness (Williams & Aaker, 2002), situations that may result in a sort of blended expression.

In summary, whereas these findings, more so the congruency effects on RTs for adult faces, formed a good basis for an emotional Stroop task that compares to the classic colour-word Stroop task in congruency effects, we also at the same time in a way validated the use of the *OpenFace* software (Baltrusaitis et al., 2018) for the succeeding study (section 2.2).

2.2 Childhood Trauma and Violent Behavior in Adolescents are Differentially Related to Cognitive-emotional Deficits

The objective of this study was first, to investigate the relationship between the number of self-reported ACEs and deficits in 'hot' vs 'cool' EFs (especially in inhibition), and how such a relationship may be correlated with violent behaviour. Second, the study sought to find out whether a condition of induced stress would affect any of the relationships established between ACE, EFs and violence under neutral and emotional contexts.

Executive functioning under neutral conditions was measured using the *standard colour-word Stroop task (SCWST)* (Stroop, 1935), while the ability to inhibit behaviour in an emotionally charged environment was measured through the *emotional facial expression*

Stroop task. Fluid intelligence was assessed using the *Berlin Test for the Detection of Fluid and Crystalline intelligence scale (BEFKI)* (Wilhelm et al., 2014), while working memory was measured the *n-back task* (Zahedi et al., 2020). Adolescents' involvement in various kinds of delinquent behavior was measured using the *Self-Report Behavior Checklist* (Kariuki et al., 2014). A short demographics' questionnaire was used to recorded participant's age, mental health history, and visual acuity.

Experiment 1 involved 53 male high school students in Nairobi County (*M*: 16.30 years, *SD* = 1.08, range = 15 - 18) who had covered at least 10 years of schooling (*M* = 11.04, SD = 1.02); came from medium to low-income background, and attended county boarding schools. In this first of two experiments, the relationship between the severity of childhood trauma and deficits in inhibitory control, WM, fluid intelligence, emotion regulation, and violence, was investigated. Results showed that ACEs were significantly correlated with deficits in inhibitory control for both neutral and emotional conditions, findings that have been consistently confirmed by previous studies (See review by De Bellis et al., 2001; Panayiotou et al., 2021). However, ACEs were not significantly correlated with fluid intelligence and WM (1-back), two functions that have been shown to be strongly related (Ackerman et al., 2005). This finding was in a way a control measure to show that participants did not necessarily differ at IQ levels per se. Previous studies have shown decrements for example in WM (e.g., Majer et al., 2010), while other studies couldn't confirm such decrements (e.g., Sheridan et al., 2017). By introducing a measure of violence as externalising behaviour, we found that responses to smile trials predicted violent tendencies, an indication that emotion regulation deficits may be a risk factor for violent offending. Whereas a study by Hughes and colleagues (2013) showed that multiple ACEs represented the risk of violent behaviour, our study was able to connect that with, not only multiple ACEs, but also the possibility of emotion regulation mechanisms among victims of high ACE scores. To further follow-up on this possibility, a second experiment was conducted, with two objectives in mind. The first was to establish the replicability of the findings of experiment 1, and second, to implement a stress protocol in order to assess EFs under 'hot' cognition.

Experiment 2 involved a larger group of 150 high school male students who filled the ACE-Q. In an attempt to oversample participants with ACE scores ≥ 4, we selected 62 participants (mean age: 16.45 years, *SD* = 1.03, range 15 – 18) who had covered at least 10 years of schooling (*M* =10.44, *SD* = 1.22). Comparable to experiment 1, participants came from medium to low income background and attended county boarding schools. In order to replicate experiment 1 findings, all procedures were as described and carried out in experiment 1, except that the difficulty of the WM task was increased by replacing the 1-back with a 2-back task, to assess whether a higher WM load would yield any relationships under experiment 2 stress condition.

As summarised in Table 3, experiment 1 findings of significant positive correlation between cumulative ACE scores and inhibitory control were replicable in experiment 2. With the facial Stroop tasks being of special interest as measures of emotion regulation abilities, experiment 2 findings replicated the increase of the facial Stroop effect with higher ACEs on the correlational and categorical analyses, and an increase of the facial Stroop for smile responses with violence in the categorical analysis. These consistent and replicable findings indicate a critical link between childhood trauma and violence by deficits in emotion regulation, reinforcing the relation of childhood trauma and violence with each other and to deficits in executive functions.

Table 3

A summary of findings showing replicable correlations and the effect of stress in the two-experiment study

	ACE		Violence		Post Stress	
	Exp.1	Exp. 2 – pre-stress	Exp.1	Exp. 2 – pre-stress	ACE	Violence
Violence	**.380****	**.358****	-	-	-	-
Color Stroop	**.356****	**.251***	.237	.234	**.284***	.120
Facial Stroop, SMILES	**.342***	**.259***	**.617****	.219	**.411****	**.289***
Facial Stroop, FROWNS	.319	.168	-.052	-.064	.168	.118
Facial Stroop, COMBINED	**.448****	**.288***	.320	.139	**.362****	.232

*** $p < .01$ (2-tailed)*
** $p < .05$ (2-tailed)*

To test the hypothesis that the interactions between ACEs, cognitive abilities, and violence (as found in experiment 1) would be modulated by a condition of stress, the TSST-G (von Dawans et al., 2011) was used to induce stress. By implementing this task, it was expected that individuals with emotion regulation deficits due to recurrent childhood adversity (ACE score ≥ 4) may have relatively more problems with EFs, especially inhibitory control, compared to those with less recurrent or no history of childhood adversity. Furthermore, those with EF deficits as measured by the facial expression Stroop task, and more so under a condition of stress would also be at a higher risk of engaging in violent behaviour. Results showed that stress increased Stroop effects for both the colour Stroop and the facial expression Stroop, indicating that the stress implementation was effective. However, the increase in Stroop effects did not change the relationship between ACE or violent behaviour with any of the emotionally neutral experimental measures. Stress neither modulated the colour Stroop effects, nor increased the congruency effects among high ACE participants. The impact of stress was mostly significant in the emotional Stroop task.

Whereas experiment 1, results showed that smile responses were related to violent offending, post-stress measures in experiment 2 indicated that the relationship between emotion regulation and violence was significantly predicted by the emotional Stroop task performance.

The relationships of ACE, EF deficits and externalization of maladaptive tendencies (such as violence for the present study) have been shown, but the underlying mechanisms of these relationships have not been exhaustively explored, but seem to have some basis in cognitive, emotional and social impairments (e.g., Felitti et al., 1998). At the emotion regulation level, early life stress leads to anomalous production of glucocorticoids by the adrenal glands leading to highly activated hypothalamus-pituitary-adrenal (HPA) axis (Gunnar & Quevedo, 2007). And whereas such a response is beneficial as it counters stress through secretion of stress alleviating biochemicals, sustained production of such chemicals (due to sustained presence of a stressor) leads to allostatic load (Fox et. al., 2015). High allostatic load has been associated with impaired brain development and maladaptive affect processing and regulation (Panayiotou et al., 2021). It therefore follows that a victim of childhood trauma facing stressful life events may experience deficiency in their internal resources to cope, yet, there is a dearth of studies that explore the interaction of ACE, EFs (especially inhibitory control), and emotional dysregulation among healthy participants, and especially differentiating ‘hot’ EFs from ‘cool’ EFs. Such a scarcity of studies is compounded by the findings by Baggetta and Alexander (2016) showing that only 8% of studies on EFs have focused on adolescents, yet it is a sensitive period of EF development, and heightened stress-induced hormonal responses, correlated with high impulsivity, and deficiencies in inhibitory control (Romeo, 2013). Such gaps motivated the current study.

In sum, the two experiments demonstrate that the ACE-EFs-externalising behaviour relationship might be better understood from a cognitive-emotional deficiencies perspective, more so under emotional contexts.

3 General Discussion

The present dissertation sought to investigate how ACEs are cumulatively related to various dimensions of EFs. Self-reported ACEs among 15-18-year-old adolescents offered unique first-hand insights into how victims at a sensitive EF developmental stage (adolescence) are affected by childhood traumatic experiences, and whether any effects on their EFs would be related to violent behaviour. In order to explore possible effects in cognitive control and emotion regulation systems, both 'cool' and 'hot' EFs were examined under conditions of non-stress and stress. To achieve these objectives, the first task of this research was a methodological issue. First, the suitability of the facial expression Stroop task as a measure of emotional inhibition was evaluated, and in the absence of EEG, EMG, or fMRI, the use of a machine classifier, - *OpenFace,* - to analyse facial expression responses recorded in video format was tested.

Analysis of the facial expression Stroop task outputs using the machine classifier confirmed that deliberate facial expressions of happiness (smiles) and anger (frowns), in response to written commands (happy, angry), are modulated by the congruency with the facial expression of background faces, modulation of which depended on the response and stimulus age. The machine classifier's output gave plausible results also in that smiles were more accurate than frowns, findings that have been shown by other methods such as EMG (e.g., Künecke et al., 2017). The accuracy of smile responses was further shown by heightened activity in both target and related AUs (AU12 + AU6) during congruent conditions. Analysing video data output using the machine classifier was also found rich in that outputs yielded activity from 17 AUs. This provides the possibility to analyse activation of other channels not related to smiles (AU12) or frowns (AU4), and might be activated under novel experimental conditions. For instance, a significant activation of AU2, somewhat unrelated to frown responses, was recorded when participants were required to frown, when the distractor face was that of an infant in distress. Such an expression might have been due to conditions compounded by unique factors, and in this case, the Kindschenschema (Glocker et al., 2009), under which infant faces with negative expressions are more likely to be appraised as needing care rather than as a threat. Thus, the AU2 activity may represent a blended expression, findings that corroborate with Ekman's (1985) 'miserable' or 'masked' expressions when one tries to conceal an expression under 'complex' conditions such as seeing the face of an infant in distress, and being required to frown at them. The machine classifier was therefore capable of analysing facial behaviour, with the video analysis yielding interpretable results for RTs, error rates, and activity. With congruency being consistently shown, the facial expression Stroop task was adopted, and due to time constraints, included only adult faces for the distractor stimuli, and measures of RTs.

The second part was the two-experiment study. Generally, results showed that fluid intelligence and working memory were not significantly affected by a history of childhood adversity. However, inhibitory control as measured by the colour Stroop task (emotionally neutral context) and the facial expression Stroop task (emotional context) seemed to be affected by history of childhood trauma, with high ACEs positively correlated with reduced inhibitory control. Smile responses for the facial expression Stroop further correlated with violent behaviour, while neutral context and frown responses did not. This may indicate that whereas some people may be able to control their impulses in emotionally neutral conditions, they may not be able to do so in emotional contexts. In a second part of this study, we replicated the findings that Stroop effects increased with ACE scores, and went a step further to show that this increase was amplified by a condition of stress in both emotionally neutral and emotional contexts. But even under a condition of stress, Stroop effects for the colour Stroop task were not correlated with externalization of violent behaviour. Unique to the facial expression Stroop task under the stress condition, Stroop effects for the smile responses not only increased with increase in ACEs, but significantly so among participants who recorded occasional involvement in violence. With a dearth of research on self-reported ACEs and how they relate to EFs and emotion regulation, especially considering both "hot" and "cool" tasks, our findings provide an important contribution to this dimension, pointing to the possibility that stressful life events may underpin the externalisation of violent behaviour among victims of childhood trauma.

The following sections summarise the unique findings on how emotionally neutral contexts (section 3.1) and emotional contexts (section 3.2) pre- and post-stress affect the manner in which ACEs interact with EF and emotion regulation, and how violent tendencies relate to such interactions (section 3.3).

3.1 Adverse Childhood Experiences and Executive Functions under Emotionally Neutral Contexts

High-exposure to ACEs was correlated with reduced inhibitory control as assessed by the colour Stroop task in experiment 1, and experiment 2 pre-stress. Such findings are in tandem with earlier findings showing deficient inhibition control as a result of childhood trauma (e.g., Marshall et al., 2016). Even among healthy participants, early childhood neglect and abuse have been correlated with deviations in cognitive control, as well as deficits in executive functioning in adulthood (Majer et al., 2010; Spann et al., 2012). In both experiments, and without a stress condition, fluid intelligence and WM failed significance when correlated with measures of ACEs. Previous findings on the relationship between ACEs and WM have not been consistent, with some findings showing decrements in WM with ACE scores (e.g., Majer et al., 2010), while other studies couldn't confirm such decrements (e.g., Sheridan et al., 2017). Whereas our findings confirm our hypothesis that high ACE impairs cognitive functions, particularly inhibitory control, there is a dearth of studies that have shown how a condition of stress may modulate the relationship between ACEs and EFs using emotionally neutral tasks

Post-stress, the positive ACE score - EF deficits correlation established in the pre-stress condition using emotionally neutral tasks were not significantly altered, indicating that performance in the colour Stroop and the *n*-back was not modulated by stress induction. These findings are at variance with findings such as the 'Easterbrook's hypothesis, which posits that under stress, selective attention is enhanced, as attention is narrowed towards the relevant and away from distracting information, thus improving performance of core EFs (Booth & Sharma, 2009). Other studies (e.g., Eysenck et al., 2007) have however argued on the contrary, that under stress, selective attention may deteriorate, leading to more errors and thus reductions in the performance of EF tasks. In particular, Shields et al. (2016) found that stress impaired working memory, cognitive flexibility, and interference control. These inconsistencies in findings may be accounted for by individual differences in baseline cognitive and emotional abilities. For instance, using the color word Stroop task, Booth and Sharma (2009) showed that under stress, participants with low WM span did not benefit from any enhancement of selective attention, therefore showed less attentional control. With the relationship between ACEs and EFs not modulated by a condition of stress for the neutral Stroop task, indicating that 'cool' EFs may not be affected by a stress condition. It was of interest to find out if that would also apply under the emotional Stroop task.

3.2 Adverse Childhood Experiences and Executive Functions under Emotional Contexts

Cumulative ACE scores were significantly correlated with the overall Stroop effect for the facial expression Stroop task, showing decrements in inhibitory control among victims of childhood adversity. Majer and colleagues (2010) have argued that early life stress is detrimental to the development of brain regions responsible for EFs, findings that have been confirmed by Spann et al. (2012), showing diminished executive functioning in children and adults with history of childhood maltreatment, and findings by Anda et al. (2016) indicating that exposure to traumatic events in the course of any of the early stages of development may cause enduring brain dysfunction. When smile and frown responses were considered separately, ACE scores ≥ 4 were associated with significantly higher delays in smile responses (but not frown responses) compared to participants with ACE scores ≤ 3. Previous studies have shown that smiles and frowns vary in the way they are mimicked. On the one hand, smiles are more acceptable and bear no personal costs, and hence mimicked more readily, while sad expressions such as frowns are mimicked less as they may be associated with aggression and perceived as socially maladaptive (Bourgeois & Hess, 2008; Künecke et al., 2017). Generally, the present study findings, especially using the emotional expression Stroop task, point to other studies that have shown that trauma impairs cognitive and affective processes. For instance, a study by Perry (2001a) demonstrated that childhood maltreatment impacts (neuro) development of children resulting in a variety of changes in brain structure, functions and stress-responsive neurobiological systems. Increased childhood trauma may therefore interfere with how individuals respond to emotional situations, and guide their actions, especially under conflict situations, as this calls for the integration of emotion regulation and cognitive control (Recio et al., 2022).

Post-stress, the facial expression Stroop task recorded delays in RTs as shown by increased Stroop effects. Past studies have shown different results. Stress has been shown to enhance selective attention by narrowing attention to the more relevant aspects of the stimulus, and away from distractor information, and thus improving EF performance under stress (Booth & Sharma, 2009). This has been demonstrated by a large body of evidence such as the 'Easterbrook's hypothesis earlier discussed, showing that stress reduced interference. However, Gur and Algom (2016) showed that under high and low stress, participants still attended to irrelevant dimensions of stimulus, concluding that better executive control, and not narrowing of attention, may account for improved selectivity under stress. Deficits in executive control may therefore compromise the ability for selective attention under an emotional context of the facial expression Stroop task and in a condition of stress. This may explain the current study findings showing EF decrements for high ACE participants, and more so under stress.

Reduced ability to react to stress has been shown to be a vulnerability factor linking childhood trauma and psychological disorders (Weltz et. al., 2016). Further, adolescence, the age of our participants, has been shown to be a period of heightened hypothalamic-pituitary-adrenal (HPA) axis reactivity, and presents changes that are sometimes externalized as heightened stress-induced hormonal responses, correlated with high impulsivity, and deficiencies in inhibitory control (Romeo, 2013). When a traumatic childhood is combined with such a crucial developmental epoch (adolescence), the effects of stress on inhibitory control, (as demonstrated by the post-stress relationship between Stroop effects and ACEs), may further be understood.

3.3 Mechanisms of Childhood Trauma and Violence

Pre-stress, our findings indicated that there are higher chances of engaging in violence among participants with cumulatively higher ACE scores relative to those with lower ACE scores. Such findings have been shown elsewhere. For instance, multiple ACEs have been shown to represent risks such as violence for the next generation (Hughes et al., 2017). Interestingly, violent behaviour did not significantly correlate with Stroop effects for the colour Stroop, but with the facial expression Stroop task, a positive and significant correlation was found for smile responses with violent behaviour. When the colour Stroop and facial expression Stroop outputs were correlated, results indicated that the two tasks were not significantly correlated, an indication that the two measures may tap into different dimensions of EFs. Botdorf and colleagues (2017) showed that an emotional Stroop task predicted laboratory risk-taking in a driving task, while the cognitive task did not. Thus, violence might be more predictable by individual differences in emotional than in non-emotional response conflict as our findings seem to indicate.

Post-stress, participants in the occasional offenders group registered delayed RTs compared to participants in the normative behaviour group, with smile responses specifically being more affected. This was further confirmed by a positive correlation between violent tendencies and Stroop effects for smile responses (and not frown responses or the colour Stroop task) after stress induction. Stroop effects for the colour-Stroop and the facial expression Stroop also differed in the way they correlated with violent aggression under the stress condition. Whereas Frequency of aggression did not significantly correlate with Stroop effects for the colour Stroop under stress, a positive and significant correlation was found for smile response (but not so for frown response) Stroop effects with violent aggression. Again, Weltz and colleagues (2016) showed that stress-reactivity, the capacity to respond to a stressor, is a vulnerability factor linking childhood trauma and associated psychological maladjustments. Adolescent victims of ACE may be able to hold impulses in check under emotionally neutral ('cool') conditions, but may have their still developing emotional regulation system weaken or compromised under affective ('hot') contexts, such as stressful life events, thus heightening their propensity for risky behaviour such as violent offending. Violence it seems, might be more predictable by individual differences in emotional tasks ('hot' EFs), and/or under a condition of stress, than in non-emotional response conflict tasks ('cool' EFs).

3.4 Conclusions

First, the present study confirmed machine classification of facial expressions as a promising low-cost tool for emotion research beyond typical chronometric effects, to measures of activity and accuracy of responses across 17 AUs, yielding richer outputs. Second, our findings show that whereas executive control is related to ACE and violent behavior in adolescents, non-emotional inhibition ('cool' EFs) tasks might be inadequate for studies that seek to relate violence with ACEs, an inadequacy that could be complimented by including emotional inhibition ('hot' EFs) in tasks battery for studies seeking to tap beyond the cognitive control circuitry to the emotional states or emotion regulation systems. Furthermore, the negative correlation between the emotional inhibitory control task (especially smile response) and violence was aggravated under stress, especially so among individuals with a history ACE scores equal to or above four, an indication that the risk for individuals with high exposure to ACEs to engage in violent behaviour is even higher in contexts that are imbued with stressful events.

3.5 Perspectives

In the current study, white faces were used as distractor stimuli in a study involving black participants. Future studies would benefit from expanding the stimulus faces to other ethnicities, and probably compare how one's ethnicity distractor face differs from other's ethnicity distractor face. Having studied only healthy participants, future studies could consider clinical groups such as autistic participants, or people suffering from social anxiety, or depression. The initial plan for this research was to study convicted violent juvenile delinquents, a plan that was thwarted by the Covid-19 pandemic, with restrictions to correctional facilities. Our participants from normal schools were not frequent violent offenders, thus future studies could look into groups of frequent violent offenders such as convicted juvenile delinquents. Findings of the current study may be optimised and used in future for psychological screening for EF deficits among children, and possibly expanded to motivate and enable training of EF domains such as inhibition control and emotion regulation in vulnerable groups such as victims of childhood trauma.

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Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt,

1. dass ich die vorliegende Arbeit selbständig und ohne unerlaubte Hilfe verfasst habe,
2. dass ich mich nicht anderwärts um einen Doktorgrad beworben habe und noch keinen Doktorgrad der Psychologie besitze,
3. dass mir die zugrunde liegende Promotionsordnung vom 3. August 2006 bekannt ist.

Berlin, den

Katembu, Stephen Muthusi

Original research articles

The dissertation is based on the following original research articles:

I Effects of Social Context on Deliberate Facial Expressions: Evidence from a Stroop-Like Task.

Reference

Katembu, S., Xu, Q., Rostami, H. N., Recio, G., & Sommer, W. (2022). Effects of social context on deliberate facial expressions: Evidence from a Stroop-like task. *J Nonverbal Behav* 46, 247-267. https://doi.org/10.1007/s10919-022-00400-x

II Childhood Trauma and Violent Behavior in Adolescents are Differentially Related to Cognitive-Emotional Deficits

Reference

Katembu, S., Zahedi, A., & Sommer, W. (under review). Childhood trauma and violent behavior in adolescents are differentially related to cognitive-emotional deficits. *Frontiers in Public Health.*

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ORIGINAL PAPER

Effects of Social Context on Deliberate Facial Expressions: Evidence from a Stroop-like Task

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Abstract
Facial expressions contribute to nonverbal communication, social coordination, and interaction. Facial expressions may reflect the emotional state of the expressor, but they may be modulated by the presence of others, for example, by facial mimicry or through social display rules. We examined how deliberate facial expressions of happiness and anger (smiles and frowns), prompted by written commands, are modulated by the congruency with the facial expression of background faces and how this effect depends on the age of the background face (infants vs. adults). Our main interest was whether the quality of the required expression could be influenced by a task-irrelevant background face and its emotional display. Background faces from adults and infants displayed happy, angry, or neutral expressions. To assess the activation pattern of different action units, we used a machine classifier software; the same classifier was used to assess the chronometry of the expression responses. Results indicated slower and less correct performance when an incongruent facial expression was in the background, especially when distractor stimuli showed adult faces. Interestingly, smile responses were more intense in congruent than incongruent conditions. Depending on stimulus age, frown responses were affected in their quality by incongruent (smile) expressions in terms of the additional activation or deactivation of the outer brow raiser (AU2), resulting in a blended expression, somewhat different from the prototypical expression for anger. Together, the present results show qualitative effects on deliberate facial expressions, beyond typical chronometric effects, confirming machine classification of facial expressions as a promising tool for emotion research.

Keywords Deliberate facial expression · Stroop effect · Mimicry · Infant faces · Cognitive control

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Introduction

Facial expressions constitute an important medium of day-to-day communication, social coordination, and interaction, enabling individuals to relate and participate in collective action. Thus, when we meet people, we usually look at their faces in order to obtain socially relevant information, which informs effective interactions (Blais et al., 2008). We display facial expressions of affective states, which, to varying extent, are deliberate, sending social signals to the communication partners, often in response to the perceived emotional state of the partner, and modulated by the situational context. The present work aims to contribute towards understanding the adaptability and flexibility of deliberate facial expressions, as captured by video analysis.

Various theories attempt to explain the mechanisms controlling facial expressions. Ekman's emotion theory views facial expressions as basic, at least partially universal, fairly fixed ways in which we communicate our internal emotional states (Ekman, 1999), yet bendable by display rules learned through socialization (Ekman & Friesen, 1969a). In contrast, according to Fridlund's (1994) behavioral ecology theory, facial expressions signify behavior intentions, and are used as tools for communicating social motives to specific audiences, whether physically present or imagined (e.g., Crivelli & Fridlund, 2018). Further, componential appraisal theorists argue that facial expressions are outcomes of the evaluation or appraisal of events in their context (e.g., Scherer, 2009); sequentially accumulated appraisal outcomes then produce unique, context- and individual-specific response patterns (Scherer, 2009; Scherer et al., 2013). Expressions of emotion have also been conceived as a motor action that may directly induce its imitation (mimicry) by an observer. Mimicry, the overt or covert spontaneous (automatic) and congruent activation of muscles serving facial expressions upon seeing the facial expression of someone else, is the basis of the matched motor hypothesis (Preston & de Waal, 2002). Experimentally, mimicry manifests in fast and unintentional activation of the facial musculature in response to facial displays of emotion in others (e.g., Dimberg & Petterson, 2000) and by mirror neurons, that is, motor neurons that are responsible for certain actions but also activated by observing others performing these actions (Ferrari et al., 2003).

However, facial displays of emotion are not just outcomes of one's own inner states and situational appraisals or an automatic reflex in response to emotional displays of others. Mimicry of emotional signals has been shown to possess some level of adaptability and flexibility determined by social factors (Hess & Fischer, 2014). In their review, Seibt et al. (2015) showed facial mimicry to be a multifactorial response modulated by personal, emotional, motivational, relational, and social characteristics of both the mimicker and the mimickee in a given context (Chartrand & Lakin, 2013; van Baaren et al., 2009). Specifically, stimuli that represent an emotional meaning, such as facial expressions do, engage both emotion regulation mechanisms and cognitive control processes in order to attend to, select, and sustain task-relevant information, which then informs appropriate facial responses (Quaglia et al., 2019; Tottenham et al., 2011).

Emotion regulation is called for when emotional stimuli automatically attract attention, hence interfering with other processes (Tottenham et al., 2011), and lead to cognitive conflict (Song et al., 2017). Such conflicts are operationalized in the emotional Stroop task where affective stimuli interfere with other, non-affective responses (Chiew & Braver, 2010). To resolve such conflicts and achieve the goals of the task (Banich et al., 2009) requires the deployment of attentional resources, such as setting up an attentional bias in perception, attenuating irrelevant information, while enhancing task-relevant information and maintaining it in working memory (Egner & Hirsch, 2005).

The need for conflict regulation holds true also for facial displays of emotion. Thus, in social contexts, facial expressions may have to be inhibited, amplified, attenuated, or simply masked with the expression of another emotion to fit the social intentions or display rules dictated by social or other situational demands (e.g., Lee & Wagner, 2002). Otte, et al. (2011a) examined how the perception of socially relevant but task-irrelevant facial expressions interacted with the execution of required expressions. A Simon-type task was used, where participants were to respond as fast as possible with a smile or a frown to the gender of a face stimulus. The face stimuli showed smiling or frowning expressions rendering the facial responses of the participants compatible or incompatible with the stimulus expression. Reaction times (RT) of the required facial expressions were measured as EMG onsets of the *m. zygomaticus major* (for smiles) and the *m. corrugator supercilii* (for frowns). RTs were shorter for compatible conditions (e.g., smile responses to smiling faces), compared to incompatible stimulus–response conditions (e.g., smile responses to frowning faces). Hence, the perceived facial expressions, even though not relevant to the task, interfered with the production of facial expressions. Similar effects were observed in a dual-task study (Otte et al., 2011b), suggesting the automaticity of the interference.

Whereas the studies of Otte and co-workers indicate that mimicry can interfere with producing emotional expressions, mimicry itself is not invariant. Bourgeois and Hess (2008) found that, irrespective of context, smiles are likely to be mimicked because they are socially acceptable, indicating affiliation intentions, and involving no personal costs. In contrast, mimicry of sad expressions comes with the risk of personal costs, and mimicry of anger may be associated with aggression and perceived as socially maladaptive (Künecke et al., 2017). Hence, facial expressions of negative emotions are less likely to be mimicked than smiles. As compared to faces of acquaintances, faces of strangers have been shown to be mimicked less (Bourgeois & Hess, 2008). Decoding same-age facial expressions has also been shown to be more accurate compared to other-age faces. (e.g., Fölster et al., 2014). Another social factor is the caregiver status of the receiver relative to the sender. For instance, according to Lorenz (1943), infant faces present a special set of cognitive representations (schema) triggered by certain anatomical characteristics, referred to as ‘Kindchenschema,’ representing features such as big eyes and round faces on a large head, inducing motivation for caregiving behavior, especially among adults (Glocker et al., 2009). Although one might expect that caregiver tendencies would inhibit mimicry of negative expressions, Korb et al. (2016) have shown that adults mimicked angry infant faces, especially when oxytocin levels in the observers were increased.

In contexts where different influences converge on an intended facial expression, mixed expressions of several emotions may be produced. For example, Ekman (1985) described ‘miserable’ or ‘masking’ smiles when one tries to conceal a smile by pulling down the lip corners, or fake smiles when the orbicularis is not involved. Further, the concept of evaluative space (Cacioppo & Berntson, 1994), that is, the simultaneous activation of happiness and sadness, has sometimes been reported (e.g., Williams & Aaker, 2002). Facial expressions change (appear and disappear) perpetually and rapidly to suit changing situations and adapt to the goal(s) being pursued. Some contexts may require the inhibition of reflexive (prepotent) nonverbal facial responses in favor of reflective (conscious) facial responses. Complex ‘mixed’ facial expressions have been demonstrated, especially when neurobiological mechanisms (e.g., mirror neurons) and visual signals (e.g., faces of others) interact in a given context (Scherer & Ellgring, 2007).

The Present Study

It was the general aim of the present study to investigate how deliberate facial expressions are influenced in their quality by the congruency with facial expressions of others, depending on whether the person (expressor) is another adult or an infant. To investigate these questions, we used a Stroop-type task that involved the production of one of two facial expressions (i.e., a smile or a frown) in response to a written verbal command presented on different background stimuli. Background stimuli were face images of adults or infants with positive, negative, or neutral expressions and scrambled faces. Unlike most other studies of this kind, the facial responses were video-recorded and analyzed with *OpenFace* software (Baltrusaitis et al., 2018), a machine classifier that identifies 17 different action units (AUs) in the face. AUs are visually distinguishable actions in the face, often but not exclusively caused by contraction or relaxation of individual facial muscles (Ekman & Friesen, 1976; Rosenberg, 2005). OpenFace software provides activity measures for each identified AU per video frame. Our main interest in the present report was how the produced facial expressions are affected by the congruency with the sender's facial expression and the caretaker status relative to the sender. We used the frame-based output of OpenFace software to determine on a trial-by-trial basis (1) The error rates and RTs of required responses, and (2) The quality of the expression by assessing all 17 identified AUs. These data allowed us to address two main questions.

Question 1: The effect of congruency of the facial expressions of background faces on deliberate expressions. Firstly, we were interested in congruency effects on the targeted deliberate expression. Specifically, we hypothesized that, (1) For congruent conditions, RTs would be shorter than in the incongruent condition, while expression accuracy and mean AU activation might be higher due to possible facilitation effects of congruence. (2) In incongruent conditions, error rates should be higher, and RT should be longer than in neutral and congruent conditions. Furthermore, the mean AU activity of the expression might be diminished as a result of possible inhibition effects of incongruence. Second, it was of interest, whether AUs that do not 'belong' to a required target expression would be co-activated as a function of congruency, possibly 'contaminating' the target responses, leading to 'mixed' facial expressions. That is, anger-associated AUs might be active during the incongruent smile condition, and smile-associated action units might be activated during incompatible frown trials.

Question 2: The effects of the age of background faces on deliberate facial expressions. Although (Korb et al., 2016) had shown that angry infant faces were also mimicked, caregiving might attenuate the interference from negative relative to positive expressions. Hence, when an infant face shows a distressed expression, mimicry may be overridden or counteracted by empathy. Therefore, one might expect a global facilitation of smiles and attenuation of frown responses when smiling infant faces are seen. Specifically, in smile production trials, facilitation by compatible background faces might be enhanced and inhibition by incompatible stimuli might be diminished by infant as compared to adult background faces. Conversely, for frown trials, facilitation by compatible negative expressions may be diminished for infant background stimuli, whereas incompatible (smiling) infant faces might lead to mixed emotional expressions.

Method

Participants

Twenty-two healthy adults, compensated with either course credits or 8 EUR per hour, participated in the experiment. Prior to participation, written informed consent was obtained. The study was approved by the Ethics Committee of the Department of Psychology of the Humboldt-Universität zu Berlin. We excluded data of three female participants due to high error rates (>40%). During video data processing, we lost one participant's video data due to technical reasons. Of the remaining 18 participants (11 females and 7 males, mean age: 26.12 years, $SD=5.6$, range 21–39), one was left-handed. None reported any history of neurological or mental disorder, and all reported normal or corrected-to-normal visual acuity. Our sample size, $N=18$, was not informed by an a priori power analysis.

Stimuli

Background stimuli were face pictures of adults and infants with different emotional expressions. The face stimuli consisted of pictures of 60 adults (30 females) from the Radboud Faces Database (Langner et al., 2010) and of 60 infants (30 girls) from online media sources. Neutral faces and scrambled faces were used as control conditions (see Fig. 1). Each face stimulus displayed a positive, negative, or neutral expression. The face pictures were matched in size and brightness. The German words for happiness and anger (i.e., *Freude, Ärger*) written in black were superimposed on the faces in the midline and at the saddle of the nose. From the viewing distance of 70 cm, the visual angle of the pictures was 4.01°×5.35°.The words Freude and Ärger, indicated participants to smile or to frown, respectively. Background stimuli were adult and infant faces, showing negative, positive, or neutral expressions and scrambled faces. Words and types of faces were combined orthogonally, yielding congruent, incongruent, or neutral expression/word combinations or combinations with scrambled faces

Procedure

Upon arrival at the lab, participants signed an informed consent form, followed by a short questionnaire to capture details of age, handedness, visual acuity, and alcohol consumption. They were then seated in a dimly lit, sound attenuated cabin in front of a computer monitor at a viewing distance of approximately 70 cm. At the bottom of the computer monitor a Sony EVI-D70P video camera was placed, which recorded the participant's facial expressions at 25 frames per second. To the left and right of the monitor a vertical strip of LEDs was placed to illuminate the participant's face.

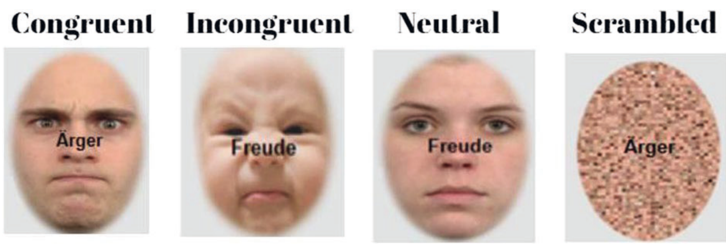


Fig. 1 Examples for face-word compound Stimuli

Apart from the videos reported here, in the present study we also recorded multichannel EEG and EMG for a different purpose, to be reported elsewhere. The EEG was recorded from electrodes placed inside an elastic cap, covering the top region of the forehead and the EMG was recorded unilaterally on the right side, with two pairs of small electrodes above the *M. zygomaticus major* and *M. corrugator supercilii,* respectively. Although, the four electrodes placed within the face and the electrode cap may have had some impact on the video data a comparison of the chronometric outcomes from EMG and video onsets indicated only small differences (for a systematic comparison of EMG and unoccluded video onsets, see Beringer et al., 2019).

The experimental procedure was controlled by "Presentation" software (version 19.0 build 11.14.16). The experiment consisted of 16 experimental conditions, each containing 60 trials, totalling 960 trials. The images were presented on a light grey background (RGB = 227/227/227), with an oval frame covering hair, ears, and neck of the faces. Trials of all conditions appeared randomly throughout the experiment, with breaks of self-determined duration after every 120 trials. At the beginning of each trial, a fixation cross appeared in the centre of the screen for 500 ms, followed by a face-word compound stimulus for 2 s. After a further 900–1000 ms (randomised) a "stop" signal was presented (for 900–1000 ms, randomised), followed by the next trial (Fig. 2).

Participants were instructed to smile or frown according to the word superimposed on the visual stimulus as fast and accurately as possible (see Fig. 2). When the "stop" signal was presented, participants should relax their facial muscles and return to a neutral facial expression. The required facial response involved the activation of AU4 (*m. corrugator supercilii*/brow lowerer) for frowns and AU12 (*m. zygomaticus major*/lip corner puller) for smiles (Tian et al., 2005). The instruction did not refer to action units or facial muscles but only asked to show a smile or a frown to the corresponding word.

Video Data Processing

The video recordings were analysed frame-by-frame with OpenFace (version 2.0.2, Baltrusaitis et al., 2018). The OpenFace algorithm had been trained on faces viewed from several perspectives and shows high accuracy for facial landmark detection and AU recognition even in non-frontal views. Outputs provided measures of activation for 17 AUs, including AU4 and AU12, the AUs taken as representing the target expressions, that is, frowns and smiles, respectively. Values around 0 indicate no activity, and value increases up to 1 and above indicate activation of a given AU. The OpenFace output text files were converted to.xlsx format in Microsoft Excel (v. 2016). Using timestamp information in the output, the data stream

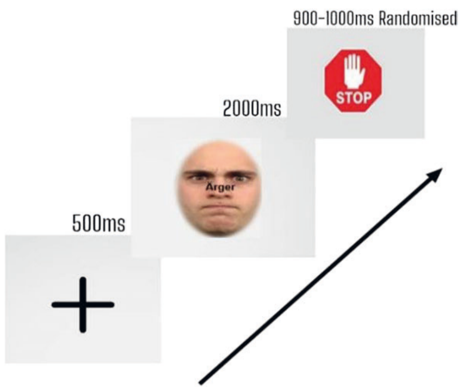


Fig. 2 Example of a trial sequence, starting with a fixation cross, followed by a word-face compound stimuli and the stop signal

containing stimulus events was merged with the excel files from OpenFace output. Using a similar procedure as reported by Recio and Sommer (2018), the datasets containing stimulus event information were processed with MATLAB (R2016a, The Math Works, 2016).

For each trial a fixed set of 90 consecutive frames was defined, including 5 pre-stimulus frames and 85 post-stimulus frames, covering a 3.6-s time interval. A baseline correction was applied in each trial by subtracting the average AU intensity scores over the 5 pre-stimulus frames (200 ms).

In order to measure participants' facial expressions and determine response correctness, data for 'frown' and 'smile' responses were parameterised from AU4 and AU12, respectively. Target versus distractor channels were defined depending on the required response per stimulus condition. That is, in trials where the word prompted a smile, AU12 was the target channel and AU4 was the distractor channel, and vice versa for frowns. Expression onset and offset thresholds were defined for each participant as 50% of the mean activity for all happy congruent trials (for AU12) all angry congruent trials (for AU4). On average, these thresholds were 0.26 (range 0.09–0.68) for AU4 and 0.81 (range 0.43–1.52) for AU12 across participants. Activity onsets occurring within the first three frames (120 ms) after stimulus onset, were considered as fast guesses and excluded from further analyses (Recio & Sommer, 2018). A response was identified as correct when activity in the target AU channel preceded any activity in the distractor AU channel and lasted for at least seven consecutive frames above threshold. All other trials were considered as errors. The threshold latency in a target trials was taken as reaction time (RT) in that trial; RTs were only analysed for correct trials (hits).

Activities for each of the 17 AUs were calculated during a period of 8-frames (320 ms) following the frame at which the threshold was reached in the target AU (=RT) in a given trial. These activities were averaged condition- and participant-wise but only when the trial was correct.

Data Analysis

The combination of required response (smile, frown) and stimulus type (happy, angry, neutral, scrambled) resulted in compatible trials (smile response plus happy face; frown response plus angry face), incompatible trials (smile response plus angry face; frown response plus happy face), neutral (smile or frown response plus neutral face), and scrambled trials (smile or frown response plus scrambled face). Data from accuracy, RTs (of correct responses), and AU mean activity were submitted to analyses of variance with repeated measures (rmANOVA) on factors congruency (congruent, incongruent, neutral, scrambled), stimulus face age (infant, adult), and the type of response (smile, frown). In an additional step, the global congruency effect was separated into an inhibition component (incongruent vs. neutral) and a facilitation component (congruent vs. neutral). Post-hoc tests were corrected for multiple testing with the Bonferroni method.

Results

Error Rates

Figure 3 shows the mean error rates for smile and frown responses in the different conditions. The present study had used both neutral and scrambled faces as reference conditions in order to assess the effects of presenting a face stimulus as compared to an unstructured

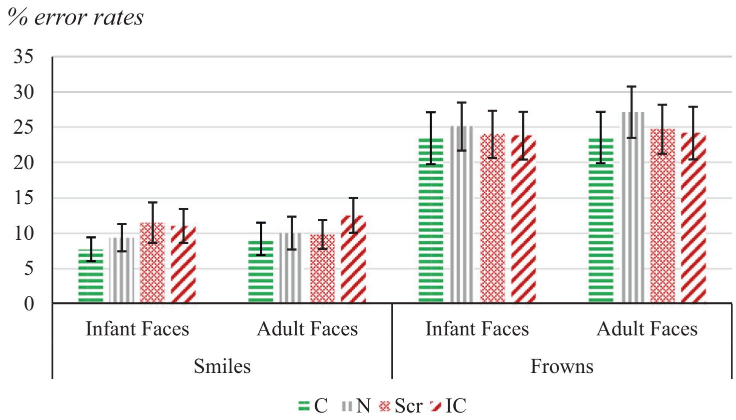


Fig. 3 Error Rates and SDs for 'Smile' and 'Frown' Responses. **C** Congruent stimulus–response conditions; **IC** Incongruent stimulus–response conditions; **N** Neutral face stimulus conditions; **Scr** Scrambled face stimulus conditions

Table 1 Error rates ANOVA for all four conditions (congruent, incongruent, neutral, scrambled), and ANOVA for error rates without scrambled face (three factor)

Conditions	Four levels of congruency			Three levels of congruency		
	df	*F*	*p*	*Df*	*F*	*p*
Stimulus face age (A)	1.17	1.42	0.25	1.17	3.11	0.09
Congruence (C)	3.51	2.19	0.10	2.34	3.30	0.049
Response (R)	1.17	15.19	0.001	1.17	16.35	0.001
A × R	1.17	0.07	0.79	1.17	0.06	0.81
A × C	3.51	0.45	0.72	2.34	0.08	0.91
R × C	3.51	3.30	0.03	2.34	7.64	0.02
A × R × C	3.51	0.85	0.48	2.34	0.57	0.57

visual noise pattern. We determined in a first step whether the error rates in the two neutral conditions were significantly different from each other, using an rmANOVA including the factors reference condition (neutral, scrambled), stimulus face age (infant, adult), and response (smile, frown). The reference conditions did not significantly differ from each other, $F(1, 17)=0.44$, $p=0.52$, $\eta^2=0.03$, and did not differentially affect error rates (see Table 1). Hence, the following rmANOVA on response and stimulus face age excluded scrambled faces from factor congruency (congruent, incongruent, neutral).

As shown in Table 2, smile responses were fairly accurate ($M=90.2\%$ correct), while frown responses were significantly less accurate ($M=75.5\%$), (F (1, 17)$=16.35$, $p=0.001$, $\eta^2=0.49$). Congruency as a main effect was significant (F (2, 34)$=3.30$, $p=0.049$, $\eta^2=0.16$) and interacted with response (F (2, 34)$=7.64$, $p=0.002$, $\eta^2=0.31$). Post-hoc tests for smile responses confirmed a main effect of congruency (F (2, 34)$=5.38$, $p<0.01$, $\eta^2=0.24$) but without significant facilitation or inhibition components relative to the neutral condition. In a post-hoc test just for frown responses, the factor congruency failed significance.

Reaction Times

As was the case for error rates, we started the analysis of RTs, measured in AU12 (smile responses) and AU4 (frown responses) (Fig. 4) by comparing the two reference conditions. Again, two reference conditions did not significantly differ (F (1, 17)$=0.08$, $p=0.79$,

Table 2 Mean accuracy rates for smile and frown responses to infant and adult face stimuli per condition

	Condition	Smiles		Frowns	
		Infants	Adults	Infants	Adults
% Correct	Congruent	0.92 (0.02)	0.91 (0.10)	0.77 (0.16)	0.76 (0.16)
	Incongruent	0.89 (0.10)	0.88 (0.10)	0.76 (0.14)	0.76 (0.16)
	Neutral	0.91 (0.08)	0.90 (0.10)	0.75 (0.14)	0.73 (0.15)
	Scrambled	0.89 (0.12)	0.90 (0.09)	0.76 (0.14)	0.75 (0.15)
Effect	Stroop (IC-C)	0.03	0.003	0.01	0.00
	Facilitation (N-C)	0.01	0.01	0.02	0.03
	Inhibition (IC-N)	0.02	0.02	0.01	0.03

$\eta^2 = 0.01$), see Table 4. The scrambled face condition was therefore dropped from the analyses of RTs. Consistent across all conditions, congruent and incongruent trials elicited the shortest and longest RTs, respectively, with neutral trials in between (see Table 3). This was confirmed by a main effect of congruency (F (2, 34) = 16.48, $p < 0.001$, $\eta^2 = 0.49$), indicating longer RTs in incongruent than in congruent conditions (Stroop effect) by $M_{diff} = 67.0$ ms. However, this pattern appeared to be modulated by both stimulus age and type of response, with smallest congruency effects for frown responses with infant background faces (Fig. 5), as reflected in a 3-way interaction of congruency, stimulus age, and response (F (2, 34) = 6.80, $p = 0.003$, $\eta^2 = 0.29$).

Post-hoc analyses of RTs of smile responses alone yielded a significant main effect of congruency (F (2, 34) = 24.48, $p < 0.001$; $\eta^2 = 0.59$) but no effect of stimulus age ($F < 1$). The factor congruency involved significant inhibition (F (1, 17) = 14.76, $p = 0.002$; $\eta^2 = 0.47$) ($M_{diff} = 38.0$ ms) and facilitation components (F (2, 34) = 13.20, $p = 0.004$; $\eta^2 = 0.44$) ($M_{diff} = 32.13$ ms) but no interactions with stimulus age.

In RTs of frown responses, the main effect of congruency (F (2, 34) = 6.24, $p = 0.01$, $\eta^2 = 0.27$), was modulated by stimulus age (F (2, 34) = 5.65, $p = 0.02$, $\eta^2 = 0.25$). When congruency was tested separately for adult and infant faces, adult faces yielded a significant main effect (F (2, 34) = 14.17, $p < 0.001$, $\eta^2 = 0.46$), whereas infant faces did not ($F < 1$). In addition, the factor congruency (for adult faces only) involved a significant facilitation component (F (1, 18) = 16.47, p = 0.003, $\eta^2 = 0.45$) ($M_{diff} = 77.7$ ms) but no inhibition component ($M_{diff} = 23.5$ ms). Therefore, the three-way interaction of congruency, stimulus age, and response seems to be due to the absence of a congruency effect for infant stimuli when frowns were the required facial response. Probably as a spin-off of the three-way

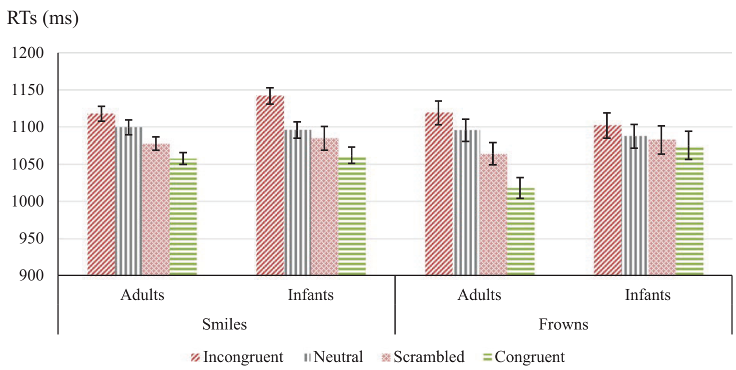
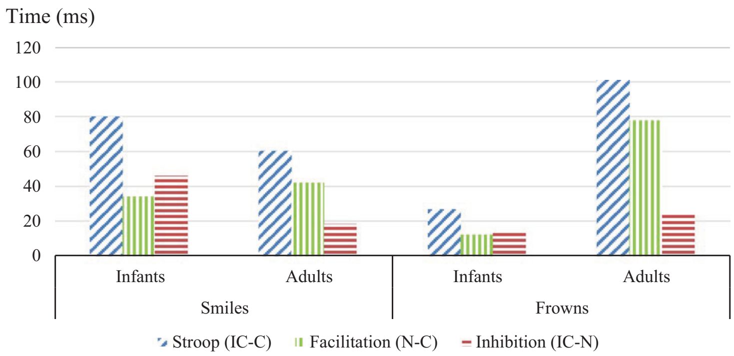


Fig. 4 Overall mean RTs (ms) and SDs for AU4 and AU12

Table 3 Overall mean RTs (Ms) and standard deviations for infant and adult face stimuli

Condition		Smile responses		Frown responses	
		Infant faces	Adult faces	Infant faces	Adult faces
RTs	Congruent	1061.94 (11)	1057.50 (8)	1075.26 (19)	1017.81 (14)
	Incongruent	1141.83 (11)	1117.84 (10)	1101.97 (17)	1118.99 (16)
	Neutral	1095.90 (10)	1099.51 (10)	1087.41 (16)	1095.53 (15)
	Scrambled	1084.71 (16)	1077.65 (9)	1082.48 (19)	1063.99 (15)
Effects	Stroop (IC-C)	79.89	60.34	26.71	101.18
	Facilitation (N-C)	33.96	42.01	12.12	77.72
	Inhibition (IC-N)	45.93	18.33	14.46	23.46

Fig. 5 Overall compatibility effects and it's components *in RTs*



interaction, there was also an interaction of stimulus age and congruency *(F* (2, 34) = 4.12, $p = 0.03$, $\eta^2 = 0.20$).

AU Activities

For the sake of simplicity, analyses of the activity of facial expressions was performed separately for smile and frown responses. Within each of these response conditions we analysed in a first step the activity of all AUs that are involved in the corresponding expression. Hence, we analysed AU12 (*Lip Corner Puller; m. zygomaticus major*) and AU6 (*Cheek Raiser; m. orbicularis oculi, pars orbitalis*) as part of the smile expression and analysed AU4 (*Brow Lowerer; m. depressor glabellae, m. depressor supercilii; m. corrugator),* AU5 (*upper lid raiser, m. lavator palpebrae sup.),* AU7 (*Lid Tightener, m. orbicularis oculi, pars palebralis),* and *AU23 (Lip Tightener, m. orbicularis oris)* as constituting the frown response (Rosenberg, 2005). For the activity of each of these AUs we assessed effects of *stimulus face age* (adult, infant) and congruency (congruent, incongruent, neutral).

In a second step, we checked whether activation of non-target AUs might leak into or mix with the target expression, especially in the incongruent conditions (for smiles: AU4, AU5, AU7, AU23; for frowns: AU6, AU12).

Finally, we assessed—for each required facial response—any experimental effects on other AUs (AU1 to AU3, AU5, AU9 to AU11, AU14, AU15, AU17, AU20, AU25, AU26, and AU45).

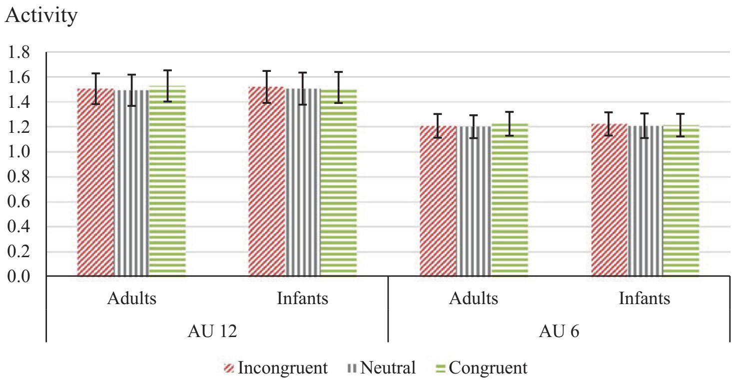


Fig. 6 Activity in AU12 and AU6 for Smile Responses. *Activity* was a measure of AUs 12 and AU 6 activation under the different stimulus conditions

Table 4 RTs ANOVA for all four conditions (congruent, incongruent, neutral, scrambled), and ANOVA for RTs without scrambled face

Conditions	Four levels of congruency			Three levels of congruency		
	df	*F*	*p*	*df*	*F*	*p*
Stimulus face age (A)	1.17	2.03	0.17	1.17	1.84	0.19
Congruence (C)	3.51	11.68	0.00	2.34	16.48	0.00
Response (R)	1.17	0.23	0.64	1.17	0.30	0.59
A × R	1.17	0.16	0.70	1.17	0.04	0.84
A × C	3.51	3.33	0.027	2.34	4.12	0.025
R × C	3.51	0.23	0.88	2.34	0.26	0.78
A × R × C	3.51	4.18	0.01	2.34	6.80	0.003

AU Activities in Smile Responses

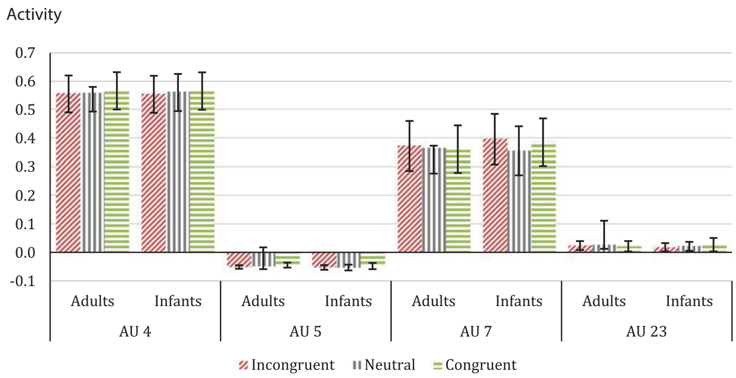
Activities of the smile-associated AU12 and AU6 are shown in Fig. 6 and Table 4. The ANOVA of AU12 activity yielded a significant main effect of congruency (F (2, 34) = 4.77, $p = 0.03$, $\eta^2 = 0.22$). Post-hoc tests of the inhibition and facilitation components showed stronger activity of AU12 in congruent than in neutral conditions (F (1, 17) = 9.53; $p = 0.014$; $\eta^2 = 0.36$), while there was no significant inhibition component (neutral vs. incongruent). ANOVA of AU6 activity did not yield significant effects.

Leakage of frown activity into required smile responses were assessed by analysing experimental effects on AU4, AU5, AU7, and AU23 within the smile condition. After Bonferroni correction, none of these AUs yielded statistically significant effects (Table 4).

During smile responses there was also no statistically significant effect in AU activity (all $ps > 0.05$) in any of the AUs that are neither related to smile or frown expressions (i.e., AU1 to AU3, AU5, AU9 to AU11, AU14, AU15, AU17, AU20, AU25, AU26, and AU45).

In sum, in deliberate smile expressions the activity of AU12 (lip raiser; *m. zygomaticus major)* increased in compatible relative to neutral trials; no other effects were observed.

Fig. 7 Mean Activity in the AUs Related to Frown Expressions. *Activity* was a measure of the intensity of AU activation under the different stimulus conditions. Values around 0 reflect no activation



AU Activities in Frown Responses

Activities in the frown response-associated AU4, AU5, AU7, AU23 are shown in Fig. 7 and Table 5. ANOVAs of the measures of each of these AUs did not yield any statistically significant effects of the experimental factors congruency or stimulus age *($p > 0.05$)*.

Leakage of smile activity into the required frown responses were assessed by analysing experimental effects on AU12 and AU6 within the frown condition. After Bonferroni correction, none of these AUs yielded statistically significant effects (Table 5).

When mean activities in AUs not belonging to the frown or smile expression (i.e., AU1 to AU3, AU5, AU9, AU10, AU11, AU14, AU15, AU17, AU20, AU25, AU26, and AU45) were analysed for the frown condition, we found the AU2 *(outer brow raiser, m. frontalis, pars lateralis)* to be modulated by an interaction of congruency and stimulus age (F (2,34) = 7.32, $p = 0.02$, $\eta^2 = 0.30$). Post-hoc analysis indicated a significant interaction of congruence by stimulus age for the facilitation component (F (1, 17) = 26.64, $p < 0.001$, $\eta^2 = 0.61$) (Table 6). That is, relative to neutral background faces, angry infant faces elicited increased AU2 activity ($M_{diff} = 0.019$), whereas angry adult background faces decreased AU2 activity ($M_{diff} = -0.020$).

In sum, frown expressions did not clearly differ in quality by smile intrusions. However, the outer brow raiser (AU2) was modulated by compatible frowning background faces in different directions, depending on whether the background face showed adults or infants (Fig. 8).

Discussion

We examined how deliberate facial expressions of happiness (smiles) and anger (frowns), prompted by written commands, are modulated by the congruency with the facial expression of background faces and how this effect depends on the age of the background face (adults vs. infants). A machine classifier for facial expressions enabled us to analyse multiple aspects of these effects. In addition to response accuracy and the chronometrics of the deliberate expressions, we considered the mean AU activity of the target expressions and leakage by non-target emotions into the target expressions.

Before discussing the main questions of this study, we should shortly mention two side issues. Firstly, we had used two kinds of reference conditions, faces with neutral expressions, and scrambled faces because we were concerned whether presenting a background face with neutral expression might interfere per se with deliberate expressions. However,

Table 5 Mean activity of AUs in different conditions during 'Smile' responses and ANOVA results

AU	Adult face			Infant face			ANOVA Factors		
							C	A	C x A
	IC	*N*	*C*	*IC*	*N*	*C*	*F*	*F*	*F*
01	−0.155	−0.146	−0.124	−0.145	−0.154	−0.146	2.0	0.78	2.8
02	−0.072	−0.073	−0.060	−0.067	−0.082	−0.075	1.72	1.50	1.84
04	−0.206	−0.212	−0.220	−0.211	−0.211	−0.213	1.00	0.04	0.56
05	−0.044	−0.048	−0.059	−0.050	−0.054	−0.059	3.50	1.42	0.30
06	1.206	1.200	1.223	1.222	1.207	1.212	1.44	0.35	1.55
07	0.227	0.213	0.242	0.221	0.225	0.221	0.31	0.11	0.74
09	0.114	0.103	0.103	0.108	0.965	0.113	1.10	0.05	1.49
10	0.498	0.503	0.520	0.525	0.513	0.508	0.15	0.77	1.42
12	1.505	1.492	1.527	1.519	1.505	1.515	4.77*	0.45	1.92
Facil	–	1.492	1.527	–	1.505	1.515	9.53*	0.00	3.09
Inhib	1.504	1.505	–	1.519	1.505	–	3.53	1.91	0.01
14	0.834	0.811	0.821	0.807	0.819	0.803	0.20	3.42	1.14
15	−0.156	−0.163	−0.166	−0.144	−0.198	−0.143	1.36	0.00	1.77
17	−0.250	−0.253	−0.270	−0.244	−0.261	−0.263	0.60	0.26	0.43
20	0.137	0.156	0.150	0.150	0.103	0.131	2.31	5.18	2.53
23	0.331	0.302	0.298	0.310	0.308	0.319	1.21	0.04	1.67
25	0.682	0.700	0.755	0.729	0.672	0.715	3.80	0.46	1.98
26	−0.163	−0.166	−0.148	−0.165	−0.134	−0.191	1.16	0.20	4.97
45	0.246	0.233	0.278	0.261	0.238	0.277	5.19	0.39	0.24

C congruence; *A* stimulus age. Shaded areas indicate the results for AU12, the main AU for smile responses

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$; $^{\dagger}p<0.1$

Table 6 Mean activity of AUs in different conditions during 'Frown' responses and ANOVA results

AU	Adult face			Infant face			ANOVA		
							C	A	C × A
	IC	*N*	*C*	*IC*	*N*	*C*	*F*	*F*	*F*
01	0.080	0.098	0.080	0.096	0.063	0.083	0.33	0.41	2.63
02	−0.061	−0.051	−0.071	−0.070	−0.084	−0.065	0.10	3.21†	7.32***
Facil	–	−0.051	−0.071	–	−0.084	−0.065	0.00	3.83	26.64***
Inhib	−0.061	−0.051	–	−0.070	−0.084	–	0.20	7.51	6.59
04	0.556	0.558	0.567	0.554	0.562	0.566	2.05	0.02	0.18
05	−0.045	−0.049	−0.045	−0.053	−0.053	−0.048	0.54	0.33	0.04
06	0.130	0.133	0.141	0.148	0.145	0.137	0.00	2.23	0.79
07	0.363	0.364	0.362	0.397	0.355	0.386	1.22	1.67	1.31
09	0.055	0.047	0.058	0.058	0.059	0.060	0.52	1.47	0.91
10	0.030	0.038	0.038	0.039	.04345	0.045	0.62	2.73	0.02
12	−0.063	−0.053	−0.059	−0.055	−0.051	−0.066	0.92	0.02	0.76
14	−0.061	−0.059	−0.057	−0.057	−0.061	−0.073	0.34	1.38	0.38
15	0.065	0.066	0.071	0.073	0.059	0.081	0.62	0.05	0.23
17	0.149	0.172	0.204	0.177	0.195	0.199	2.69	3.94	0.95
20	0.011	−0.001	0.001	0.016	−0.011	−0.005	2.69	0.76	0.30
23	0.024	0.026	0.021	0.018	0.023	0.027	0.11	0.07	0.39
25	−0.097	−0.075	−0.065	−0.063	−0.092	−0.060	1.86	1.02	1.77
26	0.019	0.000	0.015	−0.004	.0192	0.027	0.74	0.11	1.29
45	0.143	0.109	0.134	0.148	0.123	0.137	1.72	0.41	0.017

C congruence; *A* stimulus age. The shaded area indicates the results for AU4, the main AU for frown responses

* $p < .05$; ** $p < 0.01$; *** $p < 0.001$; † $p < 0.1$

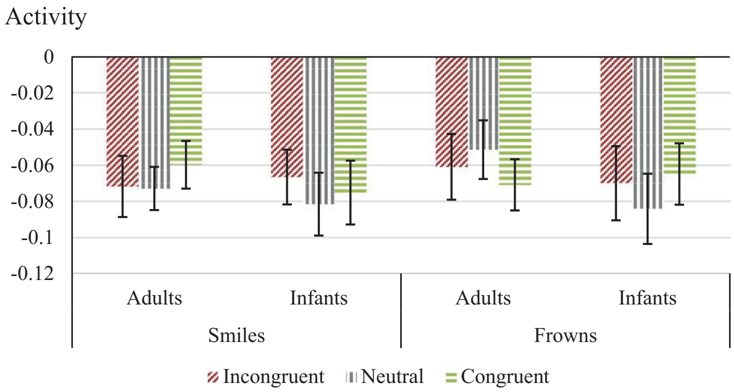


Fig. 8 Mean Activity and SDs for AU2. *Activity* was a measure of AU activation under the different stimulus conditions. Values around 0 reflect no activation

the comparison of error rates and RTs between neutral and scrambled faces did not yield notable differences, with one exception discussed below, indicating no distracting effect by a neutral background face in particular. Therefore, we simplified the analyses of congruency effects by dropping the scrambled face condition. Second, the type of deliberate response had a marked effect on error which were considerably higher for frowns than for smiles. We hold this to be partly due to the fact that in parallel to the videos, we had recorded facial EMG, requiring to place electrodes above the corrugator and zygomaticus muscles; hence the corrugator electrodes may have occluded AU4 to some extent. This conclusion is supported by the fact that the analysis of the EMG (reported elsewhere) yielded more accurate performance for frown responses than the present video analysis. Importantly, the RTs of correct responses were not significantly different for the required expression. Therefore, we believe that the video analysis yielded interpretable results and that smiles and frowns per se are similar in their demands on the participants.

The Effect of Congruency between Response and Background Expressions

The most consistent finding in the present data set are the effects of congruency. In error rates, congruency effects were seen only for smiles. However, in RTs and with adult background faces, the congruency effect was strong and indistinguishable for frowns and smiles. There was a mean increase of RTs from congruent to incongruent conditions (Stroop effect) of 67.0 ms, when averaged over both frown and smile responses. Relative to the neutral condition, there was a clear facilitation due to congruence, and inhibition due to incongruence.

The congruency effects may be explained by facial mimicry eliciting automatic matched response tendencies. Facial mimicry is considered to be rooted in perception-behaviour links where facial expressions of others are spontaneously copied by the observers (e.g., Chartrand & Bargh, 1999; Dimberg & Petterson, 2000; Otte et al., 2011a). Such mimicry involves reflexive responses with little or no cognitive conflicts, thus facilitates performance in compatible trials. In contrast, incompatible trials such as smiling at an angry face, may involuntarily activate facial expressions of the frowning distractor face stimulus as opposed to the required smile. Hence, in incompatible trials, mimicry may activate incorrect responses, or may call for a more reflective response, causing conflicts that need to be solved. Increased RTs in incompatible conditions are presumably due to the necessary and time consuming recruitment and deployment of cognitive processes required to detect and resolve conflicts in incongruent trials (Egner et al., 2008; Etkin et al., 2006).

The present results that congruency effects in RTs do not depend on the type of response appears to be at variance with the idea that mimicry is stronger in conditions with affiliative intent (e.g., Bourgeois & Hess, 2008). At the least it demonstrates that requiring frowns versus smiles does not constitute a manipulation of affiliative intent or else the congruency effect should have been smaller for frown than for smile responses. However, this was not the case for our adult background faces. Also, the more specific facilitation and inhibition components were not modulated by the type of response.

Of main interest for the present analysis were the AU activity measures provided by the OpenFace software. Hence, for each required deliberate expression, we measured the effects of congruency on the intensity of the expression itself, whether there was any leakage or intrusion from the alternative expression, and whether there was any effect on AUs not related to any of the target expressions. Activity at the AU12 for smile responses yielded a main effect of congruency, and—specifically—a significant facilitation effect (congruent vs. neutral), but no inhibition effect (neutral vs. incongruent). This indicates that the intensity of smile responses benefited from congruent conditions.

We assessed possible intrusions or leakage into required smile responses by analysing experimental effects on frown-related AUs (AU4, AU5, AU7, and AU23) within the smile condition, none of which yielded any statistically significant effects. There was also no congruency effect in AUs that were not related to any target expression. Together, these findings indicate that smile responses were robust against the intrusion of frown activity due to background distractor faces.

Activities at the frown-related AU4, AU5, AU7, AU23 were stable across all stimulus conditions, with no congruency, facilitation, or inhibition effects, and no intrusions of smile activity into the required frown response as assessed by analysing experimental effects on AU12 and AU6 within the frown condition.

In sum, the speed of smile and frown responses are remarkably and similarly sensitive to the congruency of task-irrelevant background faces. It seems that deliberate smile expressions become more intense when the background face is also smiling. In contrast, the mean AU activities of frown responses were unaffected by background faces.

The increased sensitivity to background faces during smile as compared to frown responses in terms of intensity may be complementary to findings that negative perceived emotional expressions, such as anger, are mimicked less than positive expressions (smiles). It is held that mimicry of smiles is more acceptable and bears no personal costs (Bourgeois & Hess, 2008; Chartrand & Bargh, 1999; Dimberg & Petterson, 2000; Künecke et al., 2017). Further, socialisation processes instil display rules that nurture friendliness (e.g., smiling) instead of aggression (e.g., frowning), in favour of facial expressions are socially adaptive (Ekman & Friesen, 1969a). Whereas these previous findings relate to the effects of mimicry as a function of the perceived emotion, the present findings indicate a differential role of the deliberate expression. We suggest that requiring smiles versus frowns may influence the communicative intent, facilitating mimicry during emotionally positive actions (smiles), but less so during emotionally negative actions (frowns).

The Effect of the Age of Background Faces on Deliberate Facial Expressions

The second main question of the present analysis was a comparison of adult and infant background faces. In particular, we expected that mimicry of negative infant expressions would be attenuated or even overridden by empathy or caregiving responses, possibly leading to a tendency to smile, providing comfort to the infant. This tendency should interfere with deliberate frowns directed at infants and block the facilitation of frown responses by images of infants in distress (displaying anger).

Accuracy and RTs of deliberate expressions were not affected by background stimulus age as main effects. However, RTs were significantly modulated by the interaction of face stimulus age, congruency, and type of response. Importantly, the smallest Stroop effect in this study was recorded when the target expression was frowning with infant faces in the background. Chronometric analysis found significant congruency effects with a facilitation component for frown responses to adult distractor faces but not for infant distractor faces. Considering that the congruency effect for smiles was not modulated by face age the strong modulation shows clearly that stimulus age affected the control over deliberate frown expressions. This is broadly in line with Fridlund's (1994) behavioural ecology theory that facial expressions are audience-specific tools of communicating behaviour intentions. The different congruency effects in RTs for frowns to infant and adult face stimuli may therefore represent a difference in audience. Hence, addressing an infant with a frown may be experienced as inappropriate, counteracting any tendency of mimicking both negative and positive expressions. The observed face age effect in frowns may also be explained by findings that mimicry is influenced by personal, emotional, motivational, relational and social characteristics of both the mimicker and the mimickee (Chartrand & Lakin, 2013; van Baaren et al., 2009). Specifically, cognitive representations (schemata) of infant and adult faces seem to differ and the anatomical characteristics of infant faces (Kindchenschema), such as big eyes and round faces on a large head, induce caregiving tendencies (Glocker et al., 2009). Obviously, infant faces with negative expressions are more likely to be appraised as needing care rather than as a threat.

Hence, frowning at infant faces may trigger very different mechanisms than frowning at adult faces. In contrast, there seems to be no principled difference between smiling to adult and infant faces. However, can we derive evidence from the present data on the nature of the mechanisms driving the differences between frowning at adult and infant face? One clue may come from the analysis of activities of AUs not belonging to the smile or frown expression (i.e., AU1, AU2, AU9, AU10, AU14, AU15, AU17, AU20, AU25, AU26, AU45). During the deliberate smile condition, no statistically significant activity was found, indicating no expression distortions or leakage in the form of irrelevant facial expressions. However, when activities of the AUs not belonging to the frown or smile expression were analysed during the frown condition, AU2 (*outer brow raiser)* activity was modulated by the congruent condition (i.e., angry background expressions) into opposite directions for adult and infant faces. Specifically, relative to the neutral condition AU2 activity increased for angry infant faces and decreased for angry faces of adults. This may indicate that seeing the face of an infant in distress triggers an expression that is somewhat different from the prototypical expression for anger, resulting in a blended expression (Ekman, 1985).

Generally speaking, faces of infants in distress may have initiated a different kind of reappraisal (Scherer & Ellgring, 2007), tapping into other response actions than involuntary mimicry. According to Scherer and Ellgring (2007), appraisal sequence and eventual appropriate response outcomes seem to cumulatively recruit AU2 as appraisals shift from inferences of novelty and importance (AU1 + AU2), to possible obstruction of goals (AU1 + AU2 + AU4), to situations appraised as unfair and unethical (AU1 + AU2 + AU4 + 17 + 23 + 10 + 14). Hence, the present observation indicates that during the deliberate frown condition, infant faces, especially distressed infant faces, may trigger a reappraisal of the situation differing from angry adult faces. Activation of AU2 may therefore be an accumulative effect of an appraisal of showing anger rather than empathy to distressed infants as ‘unfair’ and against caregiving tendencies (Glocker et al., 2009). This may not be the case for encountering an angry adult, in which case detection of anger and corresponding response is appropriate as it could signify danger.

Infant faces represent a unique set of conditions (Glocker et al., 2009). When used as stimuli, infant faces may present a context leading to complex ‘multimodal’ facial expressions as neurobiological bases (mirror neurons, Kindchenschema, caretaker reflex), visual signals (frowning at infant faces), and reappraisals interact. We presume that the activation of AU2 may be part of a complex multi-layered facial expression due to possible reappraisal of the faces of infants in distress under unique conditions. The “inhibition hypothesis” (Darwin, 1872) posits that highly intense facial expressions may not be subject to voluntarily control. In some situations, neuroanatomical and cultural differences may interact in a way that produces facial expressions that escape efforts to control or mask, thus emerging as leaked expressions (Ekman & Friesen, 1969b). Such leakage of expressions has been shown to be most likely under incongruent conditions (Jens, 2017). Seeing the face of an infant in distress may have elicited reactions that cannot be inhibited, and therefore will affect AU2.

Limitations and Perspectives

The present study has demonstrated that rich information can be derived from machine classifier-based video analysis about how cognitive control can modulate the quality of deliberate facial expressions beyond effects in RTs. However, the present study has some limitations that might be overcome in future work. While infant smiles are unambiguous, it is challenging to differentiate negative emotions on infant faces (Camras & Shutter, 2010), which makes it difficult to define “compatible” response conditions. As mentioned, the accuracy of recording frown responses with video may have been compromised to some extent by the EMG electrodes. Although we believe that the electrodes did not invalidate the present results, especially those from unoccluded AUs, future studies should avoid such occlusion. This seems to be all the more feasible, the accumulating evidence that machine classifiers provide rich information about both chronometry and quality of facial expressions (see also Beringer et al., 2019). Another limitation is the camera perspective; the camera recorded faces from below rather than horizontally. However, the OpenFace software algorithm was trained for different viewpoints and is able to deal with this situations, which was also our impression, when we compared video outputs from different angles. Further, the results are limited by a rather low number of participants, which requires a minimum effect size of 0.65 in order to detect a significant effect with 95% probability.

Conclusions

Previous studies have shown that in facial expression production tasks, incongruent background faces can modulate the speed of facial expressions, whether recorded with EMG or machine classifier of videos. This was confirmed in the present report for machine classifier-based analyses. Here, we go beyond these studies in at least two respects. Firstly, we used the machine classifier to assess also the quality of the responses and not just their onset speed. Thus we found that in compatible conditions, smiles are not only faster but also brighter. Second, we investigated the effects of a potential caregiving relationship to the model presented on the screen. It turned out that the chronometric pattern is very different when frowns are required to infants, both in terms of a strong attenuation of the congruency effect and in the quality of the facial expression. The required frowns showed intrusions that can be interpreted as the result of considering the required expression as unfair. Apart from these concrete findings, the present study may serve as an encouragement that the low-cost recording and machine classification of facial expressions is not only a cheap alternative to EMG recordings but may—in at least some respects—yield even richer information.

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Data Availability Data that support the findings of this article are available at https://osf.io/7zpbk/files/

Declarations

Conflict of interest The authors declare that there were no financial or other conflicts of interest in conducting this research.

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Childhood trauma and violent behavior in adolescents are differentially related to cognitive-emotional deficits

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Abstract

Converging neurobiological and epidemiological evidence indicates that exposure to traumatic events in the early stages of development, that is, adverse childhood experiences (ACEs), negatively affects the likelihood to be involved in violent behavior later in life. These problems seem to be mediated to some extent by the disruption of executive functions, in particular the ability to inhibit inappropriate actions. Here we aimed to distinguish the contribution of inhibition in non-emotional and emotional situations (i.e. emotion regulation) and assessed the modulating influence of stress, testing Nairobi county high school students. In Experiment 1, neutral and emotional inhibition, working memory, and fluid intelligence were measured alongside questionnaires about ACE and violent behavior. ACE was positively related to both non-emotional and emotional inhibition; in contrast, violent behavior was only related to deficient emotional inhibition. Experiment 2 replicated these relations in an independent sample and assessed whether they would be aggravated after acute experimentally induced stress. Stress did not significantly affect the relation of ACE to non-emotional inhibition and emotion regulation; however, it increased deficits of violent participants in their ability to down-regulate emotions. Together, results suggest that more important than impairments in non-emotional inhibition in driving violent behavior in victims of childhood trauma may be their deficits in emotion regulation, especially under stressful conditions. These novel findings open perspectives towards more targeted research and interventions.

Keywords: Adverse childhood experiences, cognitive control, emotional regulation, intelligence, working memory, violence

1 Introduction

Favorable childhood conditions offer a conducive milieu for the development of the brain that affects a wide range of psychological and cognitive components, such as inhibition, emotion regulation, attachment, self-image, and socialization (1). Successful development has been positively correlated with cognitive outcomes such as physical and mental health, happiness, and a lower likelihood of risky behavior and drug use (2). Whereas the basic foundation and general structure of the brain are provided for by genes, favorable experiences mold the neural connections that facilitate sensory, motor, and cognitive skills and behavior regulation (3), as well as emotion regulation (4). Notably, epidemiological studies have shown a high prevalence of unfavorable experiences among children (5). In the seminal 'CDC-Kaiser Permanente Philadelphia study, Felitti et al. (6) coined the term *adverse childhood experiences (ACEs)* to refer to potentially traumatic experiences in the years prior to the age of 18. Over 17,000 members of a health maintenance organization in South California took part in this study, reporting their current health status, behavior, and childhood experiences. At least 52% of participants reported one or more ACE, consisting of physical, emotional, and sexual abuse, emotional or physical neglect by caregivers, or family disruption marked by household incidences such as witnessing violence (6). Notably, poor outcomes have been shown after both single or multiple exposures to ACEs (7).

Childhood trauma has been regarded as 'an environmentally induced complex developmental disorder' (8). Unlike adulthood trauma, childhood trauma presents more detrimental consequences due to its interaction with ongoing psychobiological and neurodevelopment leading to long-lasting effects. According to (8), childhood maltreatment affects multiple densely interconnected neurobiological systems that affect EF development, as well as emotion and behavioural regulation. Adverse childhood experiences may lead to elevated levels of catecholamines and cortisol leading to accelerated loss (metabolism) of neurons, delayed myelination, abnormal synaptic pruning and inhibited neuro genesis, with MRI studies of maltreated children showing reduced intracranial and cerebral volumes compared to controls with no history of maltreatment (8). Exposure to a traumatic life event activates the hypothalamus-pituitary-adrenal (HPA) axis, prompting the adrenal glands to produce glucocorticoids (9). This allostatic response is beneficial as it leads to secretion of stress alleviating biochemicals, except, when an enduring stressful event or events in childhood leads to sustained chemical responses, referred to as allostatic load (10). High allostatic load has been associated with impaired brain development and functioning (11), destructive physiological and behavioural responses (10), and maladaptive affect processing and regulation (12). These changes may be long-lasting wounds that time may not heal (13). For instance, in adolescent victims of childhood abuse, thickness in the ventrolateral and ventromedial prefrontal cortex (PFC) and medial and lateral temporal cortex was reported to be reduced (14). Childhood adversity has also been associated with alterations in the orbitofrontal cortex (15), leading to deficiencies in adaptive decisions that require careful evaluation of future consequences (16). Additionally, the reduced thickness of the parahippocampal gyrus (PHG) may be a mediator between childhood abuse and externalizing psychopathology (14). To summarize, converging evidence from neurobiology and epidemiology has indicated that exposure to traumatic events in the course of early stages of development may cause a vulnerability to impairments in social, emotional, and cognitive abilities (3, 17), and increased risks to engage in violent behavior (10).

Several studies have found strong associations between externalizing behavior and exposure to ACEs (e.g., 18), with poor self-regulation as a developmental sequela of exposure to ACEs (e.g., 19). For example, in a longitudinal study, Widom (20) followed 1575 children (667 in the control group) over a 20-year period after reporting childhood mistreatment. They found that experiencing abuse or neglect increased the chances of being arrested as a youth by 53%. Further, exposure to childhood abuse and neglect has been positively and significantly correlated with the likelihood of arrest for violence and adult criminality, with Reavis et al. (21) reported nearly four times more ACEs in a group of adult male offenders than in a control group.

Whereas each adverse experience negatively impacts psychodevelopment, health and behaviour, individuals who record four or more ACEs have been shown to have a 4-12 times higher chances of physical and mental health related risks compared to those who record three or less ACEs (6). Such findings indicate a dose-response effect where, every additional ACE score exponentially increases the possibility of negative physical and/or mental outcomes (17). Furthermore, Dong et al. (22) found that more than 81% cases of respondents who reported a certain kind of adverse childhood experience also reported another type of childhood trauma. Clustering childhood experiences have been shown to be crucial in effective research and understanding of ACEs (23). Previous studies also suggest that there is a cumulative effect of ACEs that can be passed on through generations. Fox et al. (10) found that for every additional ACE experienced, participants' risk of becoming a serious, violent, and chronic (SVC) juvenile offender increased. Multiple ACEs have also been shown to represent risks such as violence for the next generation (24). Additionally, Guedes and Mikton (25) found that adversity in childhood was associated with intimate partner violence among adolescents.

These results were also confirmed in several meta-analyses. For instance, Braga et al. (26) conducted a meta-analysis of studies addressing childhood adversity and juvenile antisocial tendencies and demonstrated that abuse (physical, emotional, sexual) and neglect significantly increased the chances of committing violent and antisocial acts among juveniles. A subsequent meta-analysis found an association between antisocial behavior and maltreatment endured through adolescence into adulthood (27). Whether considered cumulatively, categorically, or individually, it is apparent that ACEs are associated with violent tendencies.

As reviewed above, there is strong evidence linking childhood trauma and violent behavior. This raises the question: which psychological factors connect the two phenomena. In the present study, we consider executive functions (EFs), especially inhibition, emotion regulation and working memory, and the potential mediation of stress among adolescents.

Executive Functions (EFs) represent a set of distinct and interrelated cognitive activities that aid an individual in adaptive responding and carrying out goal-oriented behavior (28). Two cognitive functions, i.e., *inhibition and working memory (WM),* are commonly considered core EFs, in which higher-order cognitive functions such as creativity, systematic decision making, problem-solving, planning, and reasoning are anchored (28, 29). *Inhibition* is associated with the self-regulation mechanisms that hinder prepotent impulses and habitual responses inappropriate for the task at hand (29). Miyake and Friedman (30) distinguished two dimensions of inhibition: prepotent response inhibition (i.e., the ability to suppress a prepotent motor response) and interference control (i.e., the ability to resist irrelevant distractor information). In a comprehensive systematic review of studies on inhibitory control among trauma-exposed youth, van der Bij et al. (3) considered 33 studies, 12 of which measured prepotent response inhibition (e.g., go/no-go tasks), 20 measured interference control (e.g., Stroop tasks), and one study measured both. Their results showed that trauma-exposed youth had deficient inhibitory control. Notably, there was no evidence that the two dimensions of inhibition were differentially related to the experience of trauma.

There are conflicting findings on the correlation between WM and ACEs. Working memory decrements have been shown among individuals with a history of childhood maltreatment (31). However, Sheridan et al. (32) found that WM was unrelated to abuse. One possible explanation is that WM depends on the type and severity of abuse (31).

Emotion regulation is a concept closely related to inhibition and refers to 'the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions' (33). Emotion regulation is called for when emotional contexts automatically draw attention, interfering with other processes (34) and causing cognitive conflict (35). Such cognitive conflicts manifest in temporal costs in the emotional Stroop task, in which emotional stimuli interfere with response time (RT) in a manner irrelevant to the color-naming task (36). For instance, when responding to the print color of neutral (e.g., 'white') or emotional words (e.g., 'death'), participants record RTs that are longer for emotional compared to neutral words (37). Recent studies have extended the Stroop task into the domain of facial expressions in which participants respond with a smile or frown to words pertaining to emotions (e.g., 'HAPPY' or 'ANGRY') written over emotional faces (e.g., happy or angry), or neutral faces (e.g., 38). Results indicated longer RTs when word meaning and the face stimulus were incongruent (e.g., 'HAPPY' word on 'angry' face) compared to congruent and neutral word-face combinations. Longer RTs can be accounted for by cognitive conflicts getting in the way of behavior regulation in emotional contexts. Resolving such cognitive conflict requires deploying attentional resources, like amplifying task-relevant stimuli while ignoring irrelevant information (39).

The relationship between emotion regulation and inhibition might be nuanced. A study by Stawski et al. (40) showed that individuals with high cognitive capabilities, even when they experienced more frequent stressful daily situations, recorded lower mood changes in response to stressful situations. However, Botdorf et al. (41) found that emotional Stroop effects but not cognitive Stroop effects predicted risk-taking in a laboratory driving task. Further, low performance during 'hot' (i.e., emotional) but not 'cool' (i.e., cognitive) tasks has been uniquely related to emotional problems (42) and may underlie violent behavior among victims of childhood adversity. Therefore, one might suggest that people can hold impulses in check under emotionally neutral (cool) conditions, but their emotional regulation and, by extension, self-regulation systems may be compromised in affective contexts. This is especially important for understanding the relationship between ACEs and EFs since ineffective emotion or cognitive inhibition could be the underlying link between ACEs and violent behavior.

There is a dearth of research investigating how stress may aggravate existing cognitive, emotional, or behavioral deficits. When demands made on an organism exceed its regulatory capacity (real or perceived), the result is stress. When one encounters stressful life events, coping with them requires varied cognitive control processes to perceive, process, and respond to the given stressor (43). Findings on the effects of acute stress on core executive functions have been inconsistent. For instance, even though stress is generally thought to impair executive functions (e.g., 44), it might benefit some aspects of cognition (45). According to 'Easterbrook's hypothesis, stress enhances selective attention by narrowing attention toward the relevant and away from distracting information, thus improving performance (46). Other findings indicate that under stress, selective attention deteriorates (e.g., 47). Further, Sänger et al. (48) showed that, under stress, people are more often than not distracted by interfering information. A meta-analysis by Shields et al. (45) has shown that stress impaired working memory, cognitive flexibility, and interference control. An explanation might be that the effects of stress on performance might be related to the baseline cognitive and emotional abilities. For instance, using the color word Stroop task, Booth and Sharma (46) found that the enhancement of selective attention under stress did not apply to participants with low working memory spans as they showed less attentional control. Also, Gur and Algomb (49) found that when presented with the color word Stroop task, participants still paid attention to both relevant and irrelevant stimuli, but there were more resources allocated to boost inhibition, leading to better executive control rather than the narrowing of attention, which accounted for to improved selectivity under stress. This study, therefore, also highlights the importance of baseline EFs abilities in stressful situations.

With studies showing that ACEs are associated with EFs and emotion regulation deficits (e.g., 6, 50), the inconsistencies about stress effects on EFs may be explained by the baseline EFs abilities. For example, stress may improve inhibitory control by enhancing selective attention among individuals with well-developed EFs (46), but this may not be the case for participants with impaired EFs, such as victims of childhood adversity . Among victims of childhood maltreatment, stressful life events or socially taxing encounters may trigger violent behavior, which may lie dormant under neutral conditions. Interestingly, according to a systematic review of recent empirical studies on cognitive abilities and EFs, Baggetta and Alexander (51) found that only 8% of 711 articles considered in the review focused on adolescents compare to children (24%), adults (32%), and older adults (20%). Additionally, Poon (42) showed a deficiency of data on the progressive development of hot versus cool EFs during adolescence.

The transition from childhood to the legal age of adulthood, that is, adolescence, is a time of continuing cognitive development (52), heightened hypothalamic-pituitary-adrenal (HPA) axis reactivity, presenting changes that are sometimes externalized as heightened stress-induced hormonal responses, correlated with high impulsivity, and deficiencies in inhibitory control (53). Some scholars have termed this period a time of storm and stress (54), and the age of all gasoline, with no brakes and no steering wheel (55). Whereas adolescence is a sensitive period for EF development, there is a dearth of research that focuses on the interaction of ACE, inhibition deficiency, and emotional dysregulation among healthy adolescents, and especially differentiating "hot cognition" (thinking under high emotional conditions) from "cool cognition" (thinking under minimal emotional stimulation).

The overarching aim of the present study is to investigate the relationship between the severity of childhood trauma and violence with deficits in inhibition, WM, fluid intelligence, and emotional regulation. After investigating the relationship between cognitive abilities and ACEs in experiment 1, we assessed the influence of acute stress on these functions in Experiment 2. Two separate samples of Kenyan adolescents from the general population with varied experiences of violent behavior and childhood trauma were used for Studies 1 and 2. Our hypotheses were (1) differential relationships exist between inhibition in non-emotional and emotional contexts with childhood trauma and violent behavior. (2) These associations will be aggravated by acute social stress.

2 Experiment 1

2.1 Methods

2.1.1 Participants

Participants were 53 male high school students in Nairobi County (*M*: 16.30 years, *SD* = 1.08, range = 15 - 18) who had covered at least 10 years of schooling (*M* = 11.04, SD = 1.02); they came from medium to low-income background, and attended county boarding schools. Prior to participation, written informed consent was obtained from each participant and the participant's parent or guardian. When the data was collected, none of the participants was currently on medication, had a history of mental or neurological health disorder, or was addicted to a substance of abuse. All participants reported normal or corrected-to-normal visual acuity and normal color vision. The study was approved by Kenya's National Commission for Science, Technology, and Innovation (NACOSTI) and the Kenyatta National Hospital-University of Nairobi – Ethics and Research Committee (KNH/UoN-ERC).

To determine the minimum sample size required to test the study hypothesis, we conducted an apriori power analysis using G*Power version 3.1.9.7 (56). To achieve 80% power for detecting a minimum effect size of 0.25 at a significance criterion of $\alpha = .05$, we required a sample size (N) of 28. Thus, the obtained sample size of *N=53 (for the colour stroop) and N=34 (for the facial expression stroop)* was adequate to test the study hypothesis.

2.1.2 General Procedure

Upon arrival at the designated data collection center, participants presented a signed informed consent from a parent or guardian given to them after expressing interest in participating in the study. They then proceeded to sign an informed consent form accepting to participate in the study, followed by a short demographics questionnaire, which recorded their age, mental health history, and visual acuity.

Several tasks were administered via laptop computers in groups of up to 5 participants. Participants sat approximately 70cm in front of a monitor (17 in., refresh rate: 100 Hz, resolution: 640 × 480 pixels).

2.1.3 Questionnaires

The *Adverse Childhood Experience* questionnaire (ACE-Q) is a 10-item scale from the seminal 'CDC-Kaiser Permanente' study (6) and measures potentially traumatic events in the years prior to age 18. The ACE-Q measures traumatic events in clusters of *abuse* (physical and emotional), *neglect* (physical and emotional), and *family disruption* (6). Despite possible distortions resulting from historical self-reporting-memory artifacts, ACE-Q scores remain a strong predictive measure, showing good psychometric properties with reliable internal consistency [Cronbach's alpha = .88 (57)], and a high correlation between its scores, mental and physical health (58). Participants responded with a *'yes'* or *'no'* to each of the 10 questions, with each *'yes'* representing a score of 1 and each *'no'* representing a score of 0. Cumulative scores, therefore, ranged from 0 to 10.

Adolescents' involvement in various kinds of delinquent behavior was measured using the *Self-Report Behavior Checklist* (59). The 30 items in the checklist are from five categories, i.e., noncompliance, truancy, violence, substance abuse, and stealing. In the present study, we focused on the violence category. Respondents marked in the checklist if they have a history of any of the listed items (e.g., bullying, fighting) and the frequency of such offending reported as either 1 (never), 2 (rarely), or 3 (often). This questionnaire was chosen because its validity had been ascertained and successfully applied to a Kenyan population (e.g., 59). Cronbach's alpha reliability coefficient of the Self-Report Behavior Checklist was 0.827. The score per category was the average of the frequencies of engaging in corresponding behaviors. Individual involvement in violent offending was then ranked as never involved/normative behavior (1-1.45), occasionally involved (1.46-2.45), and persistently involved (2.45-3)

Fluid intelligence was assessed by means of the *Berlin Test for the Detection of Fluid and Crystalline intelligence scale (BEFKI)* for Grade 8-10 (60). BEFKI is a figural reasoning scale consisting of 16 non-verbal items in the form of geometrical shapes, similar to Raven's progressive matrices. The sequence of the shapes per item changes in line with implicit rules. Participants are required to deduce those rules and choose the next two shapes in the sequence. They are given 14 minutes to do that. This was used as a measure of fluid intelligence, a construct presumed to be independent of prior learning and experience (61), with the advantage that it minimizes the effects of language, with a reliable internal consistency **(**cronbach's alpha = 0.76**).** Whereas this scale assessed fluid intelligence, it has been shown to be a valid measure of general intelligence under the prescribed time restrictions. Scores are the proportion of correctly solved items.

2.1.4 Experimental Tasks

The n-Back Task: This task is a standard 'executive' working memory task (62) and requires participants to decide if a stimulus in a temporal sequence matches an item presented n steps ago (63). Our working memory task presented letters in the middle of the monitor (1.6° matrix/eye). Participants responded with a left click on the mouse whenever a target was presented (match with a preceding stimulus). For example, when doing the one-back task in a sequence B, A, A, the final "A" in that sequence would be the target because it matches the "A" that was presented immediately (one trial) before. The test consisted of 150 trials, with 20% targets and 80% distractors. A blank interstimulus interval (ISI) was set at 1,500 ms, with minimum reaction time (RT) set at 100 ms and a maximum RT at 1,200 ms. Responses that fell outside this range were categorized as missing. There was one break that allowed participants to continue by pressing the left click on the mouse. Each participant was presented with the same random letters. We used the one-back task for Experiment 1.

The *Stroop color and word test (SCWT)* (64) was programmed in Presentation software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com). The task used here was validated in a previous study (65). The stimuli consisted of color words (e.g., *yellow*) and non-color words (e.g., *while*), written in one of four different colors (red, green, blue, and yellow). The stimuli were either congruent (e.g., *yellow* written in yellow), incongruent (e.g., *yellow* written in red), or neutral (e.g., *while* written in yellow). The neutral words were matched in length to the color words. To avoid phonological facilitation (66), the neutral words did not have a similar first letter as any of the color words used. Stimuli were presented on a grey monitor. The response keys were associated with one of the four colors, and colored stickers were used to label them accordingly. Participants were encouraged to memorize the response keys at the beginning of the experiment. Before the presentation of each stimulus word, a fixation cross was shown for 500 ms, and a 2000 ms duration was allowed for a response. Wrong responses or responses made after the lapse of this period (2000 ms) without a response were coded as incorrect. The interval between stimulus onset and the onset of the response key press was defined as the RT. Participants were presented with 30 to 45 practice trials at the beginning of the Stroop task. Only the practice trials provided feedback on whether a response was correct or not. There was a total of 250 experimental trials. The task was approximately 15 minutes, including two equally spaced breaks. As they responded to incongruent (IC), neutral (N), and congruent (C) color word combinations, the response time (RT) was the output. The difference in RT between IC and C conditions, i.e., Stroop effect, was taken as a measure of inhibitory control, with higher Stroop effects implying lower inhibition ability. The difference in RTs between N and C represented facilitation effects, while the difference in RTs between IC and N represented inhibition effects.

In the *emotional expression Stroop task* (38, 67) face pictures of 60 adults (30 males) with different emotional expressions (happy, angry, neutral) were taken from the Radboud Faces Database (68). The face pictures were matched in size and brightness. The words 'happy' and 'angry' written in black were superimposed on the faces in the midline and at the saddle of the nose (see Fig. 1). The orthogonal combination of the words (happy, angry) with stimulus expressions (positive, negative, or neutral), yielded congruent, incongruent and neutral conditions.

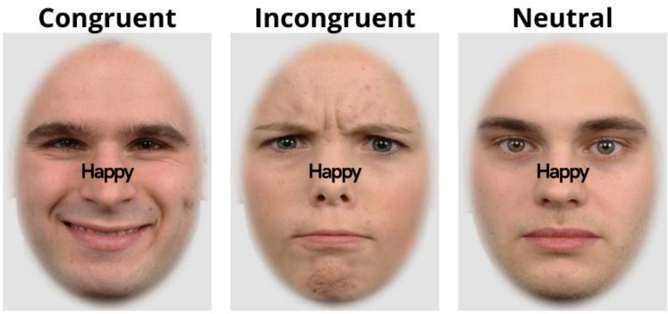

Figure 1 Examples for face-word compound stimuli.

The experimental procedure was controlled by "Presentation" software (version 19.0 build 11.14.16). At the top of the laptop computer monitor, a Logitech C270 video camera (video capture resolution, 720p) was mounted, which recorded the participant's facial expressions at 25 frames per second. It was ensured that the participant's faces were well illuminated. Stimulus presentation/onsets were marked by a tone. Audacity software was used to locate the frame numbers of the stimulus onsets. The experiment consisted of 6 experimental conditions, each containing 80 trials, totaling 480 trials. The images were presented on a light grey background (RGB = 227/227/227), with an oval frame covering the hair, ears, and neck of the faces. Trials of all conditions appeared randomly throughout the experiment, with breaks of self-determined duration after every 120 trials. A fixation cross appeared in the center of the screen for 500 ms at the beginning of each trial, followed by a face-word compound stimulus for 2000 ms. Thereafter, a further 900-1000 ms (randomized), a "stop" signal was presented (for 900-1000 ms, randomized), followed by the next trial (Fig. 2).

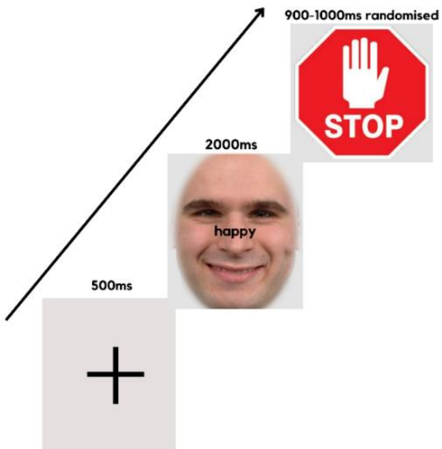

Figure 2 Example of a trial sequence, starting with a fixation cross, followed by a word-face compound stimulus and the stop signal.

The instructions were for participants to frown or smile as fast and accurately as possible, as per the word superimposed on the visual stimulus. Participants would then relax their facial muscles and return to a neutral expression upon pre4sentation of the "stop" signal (see Fig. 2). Facial response so produced involved the activation of AU4 (*m. corrugator supercilii*/brow lowered) for frowns and AU12 (*m. zygomaticus major*/lip corner puller) for smiles (69). The instructions only mentioned reponses of showing a frown or a smile corresponding to the superimposed word, without referring to facial muscles or action units involved. In this task, as participants responded to incongruent (IC), neutral (N), and congruent (C) face-word combinations, and response time (RT) was the output. The difference in response time (RT) between IC and C conditions, i.e., the Stroop effect, was taken as a measure of emotional inhibitory control, with higher Stroop effects implying lower inhibition ability. The difference in RTs between N and C represented facilitation effects, while the difference in RTs between IC and N represented emotional inhibition effects. The emotional Stroop task was validated in a previous study (67).

2.1.5 Video Data Processing

The OpenFace software (version 2.2.0, Baltrusaitis et al., 2018) was used to analyze frame-by-frame, the video recordings. Outputs provided measures of activation for 17 AUs, including AU4 and AU12, the AUs taken to represent the target expressions, frowns, and smiles, respectively. Value increases up to 1 and above indicated activation of a given AU, while values around 0 indicate no activation. The OpenFace output text files were converted to .xlsx format in Microsoft Excel (v. 2016). Using timestamp information in the output, the data stream from audacity containing stimulus events (frame numbers) was merged with the excel files from OpenFace output. Using a procedure similar to that reported by Recio and Sommer (70), MATLAB (R2016a, The Math Works, 2016) was used to process the datasets containing information on stimulus events.

A fixed set of 90 consecutive frames was defined For each trial. This included 5 pre-stimulus frames and 85 post-stimulus frames, covering a time interval of 3.6 seconds. In each trial, a baseline correction was applied by subtracting the average intensity of AU scores over the five pre-stimulus frames (200 ms).

Data for 'smile' and 'frown' responses were parameterized from AU12 and AU4 respectively, to determine participants' facial expressions and assess correctness of response. Target versus distractor channels were defined depending on the required response per stimulus condition. For instance, in trials where the word prompted a frown, AU4 was the target channel, and AU12 was the distractor channel. The onset, offset, and duration of target and distractor AUs were measured for each trial. The onset and offset of a given expression was measured by defining a threshold value for AU activation in each target channel for each participant. Activity onsets occurring within the first 120 ms (three frames) after stimulus onset were excluded from further analyses as they were considered fast guesses (70). When activity in the target AU channel preceded any activity in the distractor AU channel and lasted for at least seven consecutive frames above the threshold, such a response was considered as correct. All other trials were considered errors. RTs were only analyzed for correct trials (hits).

2.1.5 Statistical methods

In this experiment, correlational analyses were used. If any variable involved in a correlation was not normally distributed, Spearman's rank correlations were used; otherwise, Pearson correlations were applied. *Stroop effects* in the Color Stroop and the facial expression Stroop tasks were quantified as the RT difference between the incongruent and congruent conditions. For a categorical analysis of these results please see the appendix (Table A3).

2.2 Results

2.2.1 Descriptive statistics

Participants reported ACE scores ranging from 0 to 9 (M=2.90, SD=1.86). The most common forms of childhood trauma among the participants were physical and emotional abuse, while sexual abuse was the least prevalent (Table 1). As to be expected, ACE scores were not normally distributed (Skewness = 1.51, Kurtosis = 1.41, Shapiro-Wilk's test for normality of distribution: $p = 0.01$).

Table 1
Number and frequency of ACE scores in the sample of Experiment 1 (N= 53)

ACE Category		**Number**	**Frequency (%)**
Abuse	Emotional	23	43.4
	Physical	27	50.9
	Sexual	2	3.8
Neglect	Emotional	17	32.1
	Physical	14	26.4
Family Dysfunction	Parental separation/divorce	14	26.4
	Domestic violence	17	32.1
	Household substance abuse	21	39.6
	Household mental illness	11	20.8
	Incarcerated family member	7	13.2

In the *Self-Report Behavior Checklist,* 50% of all participants reported normative behavior, while the others reported histories of occasional violent behavior. Accordingly, violent behavior scores were not normally distributed (Skewness = 0.72, Kurtosis = -2.80; and Shapiro-Wilk's test normality of distribution: $p = 0.00$).

2.2.2 Correlational analyses

Table 2 presents a correlation matrix across the dependent variables in Experiment 1. Since ACE and violence scores are continuous variables, correlations were across cumulative scores. If any variable involved in a correlation was not normally distributed, we used Spearman's rank correlations; otherwise, Pearson correlations were applied.

Table 2
Correlation matrix for all dependent variables in Experiment 1

	ACE	Violence	Gf	Working Memory	Color Stroop	Facial Stroop SMILES	Facial Stroop FROWNS
Violence	**.380****						
Gf	-.126	-.184					
Working Memory	-.012	-.230	.094				
Color Stroop	**.356****	.237	-.088	-.058			
Facial Stroop, SMILES	**.342***	**.617****	-.082	-.329	.242		
Facial Stroop, FROWNS	.319	-.052	.237	-.055	.239	.338	
Facial Stroop, COMBINED	**.448****	.320	.119	-.116	.291	**.701****	**.864****

*** p < .01 (2-tailed)*
** p < .05 (2-tailed)*

2.2.3 Color Stroop task

Stroop effects were found to be positively correlated with the cumulative ACE scores ($r(51) = .36, p = .01$), while the correlation of the color Stroop effect with violence scores was also positive but only a trend ($r(51) = .24, p = .09$). There were no significant correlations with the facilitation component (C-N) ($r(51) = .26$, $p = .18$) or inhibition components (IC-N) of the Stroop effect ($r(51) = .25$, $p = .21$).

2.2.4 Facial expression Stroop task

Stroop effects for the facial expression Stroop task (averaged across smiles and frowns) did not correlate significantly with cumulative *ACE* or *violence* scores (see Table 2). However, *Stroop effects* for smile responses were significantly correlated with cumulative *ACE* ($r(32) = .34$, $p = .048$), and *violence* scores ($r(32) = .68$, $p = .00$), whereas frown response *Stroop effects* when correlated with *ACE* yielded only a trend ($r(32) = .32$, $p = .06$).

2.2.2.2 Working Memory and Fluid Intelligence

Working Memory and Fluid Intelligence were considered control variables for which we did not expect a relationship to ACE and non-normative behavior. Indeed, no significant correlations were found for cumulative ACE scores and working memory (r(51) = -.01, p = .93), or for violence and working memory (r(51) = -.23, p = .10). Further, no significant correlations were found for cumulative ACE scores and Gf (r(51) = -.13, p = .37), or for violence and Gf (r(51) = -.18, p = .19).

2.3 Discussion

The aim of Experiment 1 was to examine how ACEs and violent behavior relate to various dimensions of EFs. To reach this aim, cognitive and emotional inhibition, fluid intelligence, and WM were measured in a sample of 53 male high school students in Nairobi with various experiences of ACEs. The results showed a significant relationship between ACEs and aggression with cognitive and emotional inhibition but not with fluid intelligence and WM.

Together the results of Experiment 1 confirm that ACEs are associated with cognitive inhibition deficits. Here we also show that deficiencies in emotion regulation are related to ACEs and represent a risk factor for violent offending.

3. Experiment 2

The aim of Experiment 2 was, first, to replicate the findings of Experiment 1, especially with respect to the novel facial expression Stroop task with the same procedure. Notably, as we did not find any significant correlation between WM and ACEs or violent behavior, we decided to replace the one-back task with a more demanding two-back version. This change would address whether the previous null results were related to ceiling effects (71) or to the specificity of ACEs' impact on cognitive and emotional inhibition.

The second and more critical question of Experiment 2 was whether stress alters the relationships observed in Experiment 1. Here, we expected that stress would further aggravate any deficits in inhibition, especially concerning emotional responses. To address these two aims, Experiment 2 was conducted in two sessions, the first of which was identical to Experiment 1. The second session, however, started with a stress-inducing social task, followed by the same cognitive tasks used in the first session.

3.1 Methods

3.1.1 Participants

From a larger group of 150 high school male students who filled the ACE-Q, we selected 62 participants (mean age: 16.45 years, *SD* = 1.03, range 15 – 18) who had covered at least 10 years of schooling (*M* =10.44, *SD* = 1.22), attempting to oversample participants with ACE scores ≥ 4. As in Experiment 1, participants came from medium to low-income backgrounds and attended county boarding schools. Written informed consent was obtained from each participant and his parent or guardian. When the data was collected, none of the participants was ill, on medication, had a history of mental or neurological health disorder, or was addicted to a substance of abuse. All participants reported normal or corrected-to-normal visual acuity and passed a color vision test.

We determined the number of participants by conducting a power analysis using G*Power version 3.1.9.7 (Faul et al., 2007). To achieve 95% power for detecting a minimum effect size of 0.25 at a significance criterion of α = .05, A sample size (N) of 44 would be required. Thus, the obtained sample size of *N=62* was adequate to confirm the study hypothesis.

3.1.2 Materials and Procedure

In order to induce stress, we used the Trier Social Stress Task (TSST), which is considered a gold standard for inducing stress in humans (72); here, we used the group format of this task, the *TSST-G* (73). The TSST-G engages participants in public speaking and public mental arithmetic, with explicit elements of social evaluation and uncontrollability. Such tasks have been shown to arouse the hypothalamic-pituitary-adrenal axis - a core stress response system - and the autonomic nervous system among healthy humans in laboratory settings (74). The stress manipulation with the TSST-G (73) consists of three stages. In *Stage I,* a ten-minute preparation and anticipation period, participants receive instructions pertaining to their tasks and are given pencils and paper to prepare a speech to convince a selection committee about their suitability for a job of their choice. The instructions end with informing the participants about an unspecified task to come later. *Stage II* consists of a 12-minute mock job interview as a public speaking task, where participants are requested to introduce themselves for two minutes to a selection committee of two, seated in front of the group. The two evaluators are presented to the participants as experts in non-verbal behavior and are to withhold verbal or non-verbal feedback. However, they prompt the participants to continue talking and ask some prepared questions every time the participants fall silent. *Stage III* consists in an eight-minute arithmetic task (the previously announced 'unspecified task'). Here participants are required to serially subtract a number (e.g., 16) from a larger starting point (e.g., 4858). Different numbers are given to each participant. In the event that a participant makes a mistake, they are stopped by a committee member and required to start again from the beginning. Each participant is given up to 80 s of this task. In Stages II and III, participants perform the tasks one by one in turn in the presence of all other participants.

All tasks and questionnaires used in Experiment 2 were identical to Experiment 1, except for the 2-back task replacing the 1-back task, as explained above. Immediately after stress induction, participants repeated the three experimental tasks: (1) the two-back (WM) task, (2) the color Stroop, and (3) the facial expression task. At the end of the experiment, participants were briefed about the experiment's aims and goals and that all procedures were for experimental purposes.

3.1.3 Statistical methods

The statistical methods used to test the relation between the continuous variables were the same as in Experiment 1. However, in order to assess the effects of stress on these relations, we had to dichotomize participants into groups of low and high ACE and low and high violence and apply analyses of variance (ANOVA) because the distribution of these variables did not allow the application of regression methods which require normal distributions.

3.2 Results

3.2.1 Self-reported ACEs

The ACE scores ranged from 0 to 10 ($M = 3.34$, $SD = 2.51$); 51.6 % of respondents had experienced four or more ACEs. Table 2 shows the frequencies of the ACE scores across the three categories. As to be expected, ACE scores were not normally distributed (Skewness = 0.41, Kurtosis = -1.36, Shapiro-Wilk's test for normality of distribution: $p = 0.01$).

Table 4

Frequency of ACEs in the surveyed population

ACE Category		Number	Frequency (%)
Abuse	Emotional	32	51.6
	Physical	30	48.4
	Sexual	12	19.4
Neglect	Emotional	23	37.1
	Physical	6	9.7
Family	Parental separation/divorce	18	29.0
Dysfunction	Domestic violence	15	24.2
	Household substance abuse	22	35.5
	Household mental illness	11	17.7
	Incarcerated family member	13	21.0

3.2.2 Violent behavior

Slightly more than half of the participants (56.5%) reported normative behavior (i.e. had not been involved in violent behavior), while 43.5% reported occasional involvement in violent behavior. As to be expected, violent behavior scores were not normally distributed (Skewness = 0.72, Kurtosis = -2.80, Shapiro-Wilk's test for normality of distribution: $p = 0.00$).

3.2.3 Correlational and categorical analyses

Table 4 presents the correlation matrix for all dependent variables in Experiment 2. If any variable involved in a correlation was not normally distributed, we used Spearman's rank correlations; otherwise Pearson correlations were applied. Further, where correlations were significant, a split ANOVA was carried out for the two independent variables categorized as *ACE* ≤ 3 (low) versus ≥ 4 (high) and *violence, normative* versus occasional.

Table 5

Correlation matrix for all dependent variables in Experiment 2

Correlations

	ACE	Violence	Gf	WM Pre-stress	WM Post-	Color Stroop Pre-stress	Color Stroop Post-stress	Facial Stroop Smiles Pre-stress	Facial Stroop Smiles Post-stress	Facial Stroop Frowns Pre-stress	Facial Stroop Frowns Post- stress	Facial Stroop Pre-stress
Violence	.358**											
Gf	-.181	-.009										
WM Pre-stress	-.007	-.020	.033									
WM Post-stress	-.073	-.117	-.024	.346**								
Color Stroop Pre-stress	.251*	.234	.118	.396**	.204							
Color Stroop Post-stress	.284*	.120	.131	-.009	.187	.280*						
Facial Stroop Smiles Pre-stress	.259*	.219	.179	.175	.140	.388**	.308*					
Facial Stroop Smiles Post-stress	.411**	.289*	-.032	.115	.054	.163	.388**	.385**				
Facial Stroop Frowns Pre-stress	.168	-.064	.017	-.083	-.069	-.104	-.200	.141	.095			
Facial Stroop Frowns Post- stress	.168	.118	-.078	.031	-.175	.101	.078	.082	.229	.204		
Facial Stroop Pre-stress	.288*	.139	.134	.073	.063	.247	.055	.726**	.296*	.735**	.219	
Facial Stroop Post-stress	.362**	.232	-.060	.099	-.091	.156	.249	.268*	.748**	.207	.794**	.330**

** $p < .01$(2-tailed).
* $p < .05$ (2-tailed).

3.2.4 Color Stroop task

When the Stroop effects (incongruent minus congruent) from the color Stroop task were subjected to a Spearman's rank correlation, correlations were modestly positive with cumulative *ACE* scores, both pre-stress *(r = .25, p = .05)* and post-stress *(r = .28, p = .03)*. However, correlations were not significant with violence (See Table 4).

The RTs in the color Stroop task were subjected to ANOVAs with split-group factors *ACE* and *Violence*, with the repeated measures on congruency (C, N, IC) and Stress (pre-stress and post-stress). Both ANOVAs showed strong main effects of congruency (Table 5).

Table 6

Experiment 2 RTs split ANOVA for Congruent, Incongruent, and Neutral conditions for the SCWT and the facial expression Stroop tasks before and after stress induction:

Group Factor	*Source*	*df*	*F*	*p*	*η2*
		Color Word Stroop			
ACE	*Congruency (C)*	*2,120*	*206.58***	*00*	*.78*
	C x ACE	*2,120*	*4.71**	*.01*	*.07*
	Stress (S)	*1,60*	*0.02*	*.89*	*.00*
	S x ACE	*1,60*	*2.57*	*.11*	*.04*
	C x S	*2,120*	*2.26*	*.11*	*.04*
	C x S x ACE	*2,120*	*.38*	*.69*	*.01*
	#Facilitation: C	*1,60*	*46.91***	*.00*	*.44*
	#Facilitation: C x ACE	*1,60*	*2.00*	*.16*	*.03*
	#Inhibition: C	*1,60*	*158.11***	*.00*	*.87*
	#Inhibition: C x ACE	*1,60*	*2.64*	*.11*	*.04*
Violence	*C*	2,120	201.43**	.00	.77
	C x Violence (V)	2,120	2.46†	.09	.04
	S	1,60	0.03	.87	.00
	S x V	1,60	0.46	.50	.01
	C x S	2,120	2.34	.10	.04
	C x S x V	2,120	1.43	.24	.02
		Facial Expression Stroop			
ACE	*C*	*2,120*	*217.74***	*.00*	*.78*
	C x ACE	*2,120*	*8.87***	*.00*	*.13*
	S	*1,60*	*0.11*	*.92*	*.00*
	S x ACE	*1,60*	*1.65*	*.20*	*.03*
	R	*1,60*	*0.40*	*.53*	*.01*
	R x ACE	*1,60*	*0.17*	*.69*	*.00*
	C x S	*2,120*	*4.45**	*.01*	*.07*
	C x S x ACE	*2,120*	*0.80*	*.45*	*.01*
	C x R	*2,120*	*2.37*	*.10*	*.04*
	C x R x ACE	*2,120*	*0.43*	*.65*	*.01*
	R x S	*1,60*	*4.99**	*.03*	*.08*
	S x R x ACE	*1,60*	*0.05*	*.82*	*.00*
	C x S x R	*2,120*	*2.51†*	*.09*	*.04*
	C x S x R x ACE	*2,120*	*0.71*	*.50*	*.01*

	#Facilitation: C	*1,60*	*64.86***	*.00*	*.52*
	#Facilitation: C x ACE	*1,60*	*4.56*	*.12*	*.07*
	#Inhibition: C	*1,60*	*132.69***	*.00*	*.69*
	#Facilitation: C X ACE	*1,60*	*3.50*	*.21*	*.69*
Violence	*C*	*2,120*	*199.84***	*.00*	*.77*
	C x V	*2,120*	*1.88*	*.16*	*.03*
	R	*1,60*	*0.41*	*.53*	*.34*
	R x V	*1,60*	*0.00*	*.99*	*.00*
	S	*1,60*	*.11*	*.74*	*.00*
	S x V	*2,64*	*2.19*	*.15*	*.04*
	C x R	*2,120*	*3.00**	*.05*	*.05*
	C x R x V	*2,120*	*3.80**	*.03*	*.06*
	C x S	*2,120*	*5.62**	*.01*	*.09*
	C x S x V	*2,120*	*3.37**	*.04*	*.05*
	R x S	*1,60*	*4.52**	*.04*	*.07*
	R x S x V	*1,60*	*0.71*	*.40*	*.01*
	C x S x R	*2,120*	*2.01*	*.14*	*.03*
	C x S x R x V	*2,120*	*1.522*	*.22*	*.03*
	#SMILES: C	*2,120*	*113.34***	*.00*	*.65*
	#SMILES: C x V	*2,120*	*6.04***	*.00*	*.10*
	#SMILES: C x S	*2,120*	*9.24***	*.00*	*.13*
	#FROWNS: C	*2,120*	*86.30***	*.00*	*.59*
	#Facilitation: C	*1,60*	*60.89*	*.00*	*.50*
	#Facilitation: C x V	*1,60*	*0.18*	*.81*	*.00*
	#Facilitation: C x R x V	*1,60*	*1.27*	*.78*	*.02*
	#Inhibition: C	*1,60*	*133.66*	*.00*	*.69*
	#Inhibition: C x R x V	*1,60*	*6.58**	*.04*	*.10*
	#Facilitation: C X V	*1,60*	*2.19*	*.42*	*.04*

* $p < .05$; ** $p < .01$; † $p < .1$

Note: # Post-hoc tests (only significant results are reported)

For the group factor *ACE,* ANOVA replicated the two-way interaction with *congruency* and *ACE.* Interactions with stress failed significance. As shown in figure 5, the Stroop effect was larger in the high ACE than in the low ACE group. For the group factor *Violence,* ANOVA (Table 5) found a weak trend for the two-way interaction effect of *congruency* and *violence*.

Accuracy rates were largely in line with the RTs results (see Table A2)

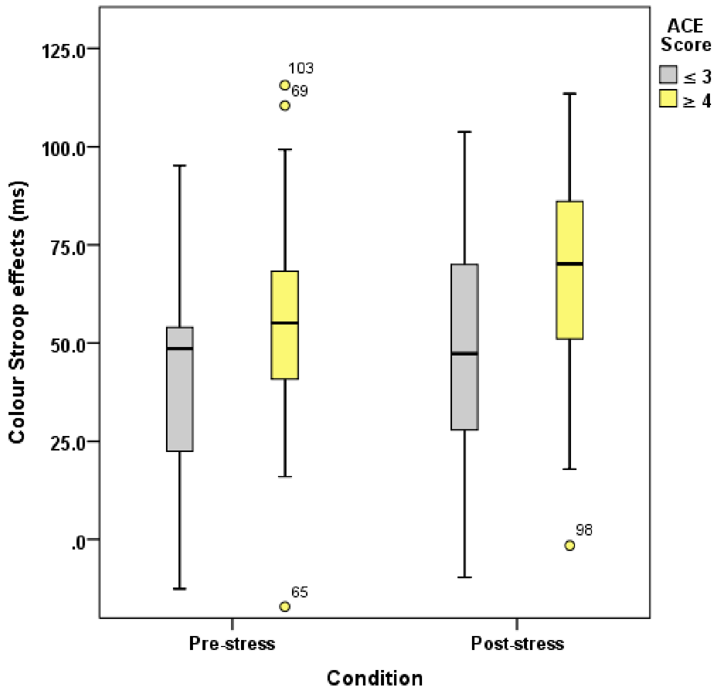

Figure 5 Boxplots for the color word Stroop effects, separated for the ACE-related participant categories, pre and post-stress conditions

3.2.5 Facial expression Stroop task

Stroop effects for smile responses (incongruent minus congruent) yielded a modestly positive but significant Spearman's rank correlation with cumulative ACE scores, pre-stress $(r = .26, p = .04)$ and medium-sized correlations post-stress $(r = .46, p = .00)$. Smile response *Stroop effects* pre-stress correlated weakly with measures of *violence* $(r = .22, p = .09)$, but were modest in size and significantly correlated post-stress $(r = .29, p = .02)$. As a follow-up to these correlations, we assessed the Stroop effects for the *violent* group pre- and post-stress. We found that for smile responses, the difference in stroop effects between pre- and post-stress condition was 13.4 ms for the normative violence group, and 36.1 ms for the occasional violent group.

Frown responses yielded no positive correlations with ACE or violence (Table 4).

Separate ANOVAs of RTs with group factors ACE and Violence, including repeated measures on congruency (C, N, IC), response (happy, angry), and stress (pre-stress and post-stress) (see Table A7) both yielded main effects of congruency and Response and interactions of Response x Stress and Congruency x Stress, confirming the effectiveness of the stress procedure.

The ANOVA for group factor *ACE* also indicated a two-way interaction with Congruency and a weak trend for the three-way interaction Congruency x Stress x Response (see Table A7). As shown in Figure 6, participants with low ACE scores showed smaller Stroop effects (IC-C) than participants with high ACE scores for both smiles and frowns.

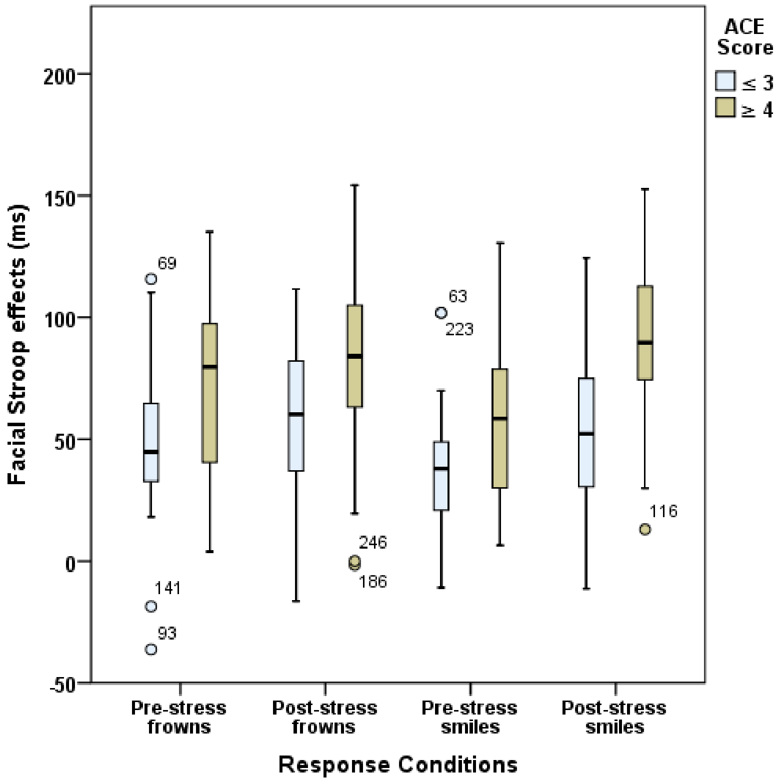

Figure 6 Boxplots for Stroop effects in reaction times for the facial expression Stroop task for the ACE-related participant categories. Note, the interaction ACE x Congruency x stress was a statistical trend

The ANOVA with violence as group factor yielded additional three-way interactions of congruency x response x violence, and congruency x stress x violence. The congruency x response x violence interaction effect seemed to be associated more with smile responses as post-hoc analysis yielded significant interaction effects of congruency x violence, and congruency x stress for smile response but not frown responses (see Table A7). As shown in Figure 6, participants who reported occasional violence recorded significantly higher Stroop effects compared to those with normative scores. Such differences in Stroop effects were more pronounced for the smile responses compared to the frown responses. Specifically, violence interacted with the inhibition component, and especially, the inhibition of smile responses as indicated by a significant congruency x violence interaction $(F\ (1, 60) = 12.85, p = .00; \eta^2 = .18)$ for smile responses but not for frown responses $(F\ (1, 60) = 2.23, p = .14; \eta^2 = .04)$.

As indicated by the congruency x stress x violence interaction, and illustrated in Figure 7, the congruency effect (for both smiles and frowns) was more pronounced after stress than before stress. In a separate ANOVA, the congruency x stress interaction for the low violence group was not significant $(F\ (2, 68) = 0.76, p = .47; \eta^2 = .02)$, but was significant for the high violence group $(F\ (2, 52) = 7.70, p = .00; \eta^2 = .23)$. For the low violence group, Stroop effects in the pre- and post-stress conditions (averaged across both frown and smile responses) differed by 8.18 ms, while for the high violence group, Stroop effects for pre- and post-stress conditions differed by 31.32 ms.

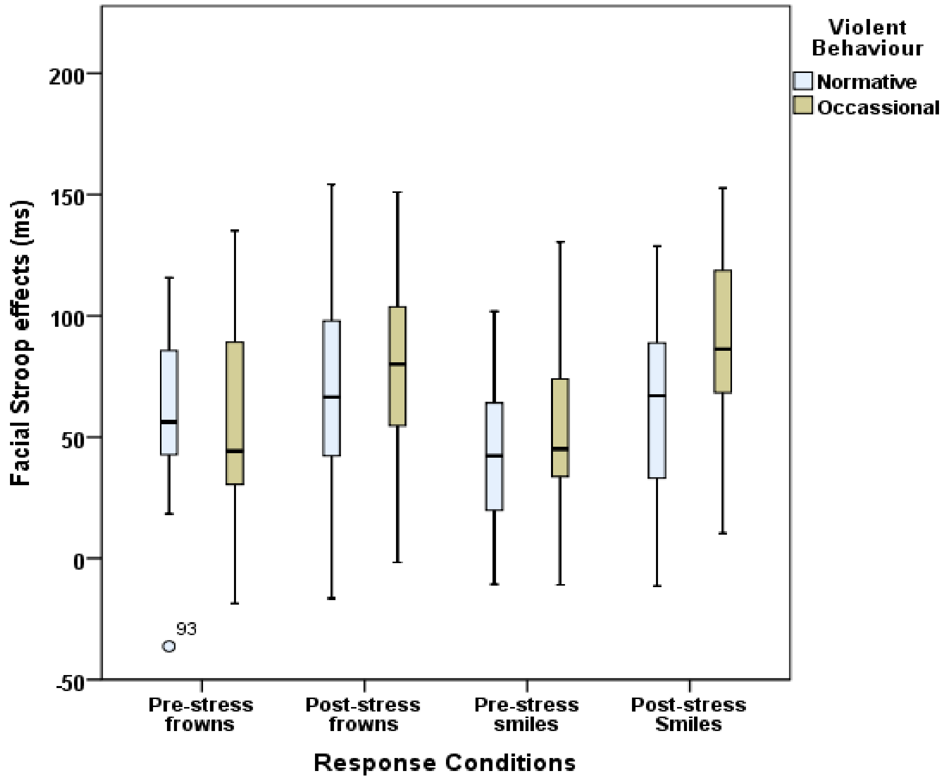

Figure 7. Boxplots for Stroop effects for the facial expression Stroop task for the violence category

3.2.6 Working Memory and Fluid Intelligence

As in Experiment 1, no significant correlations were found for cumulative ACE scores and Gf (r = -.18, p = .16), or for violence and Gf (r = -.01, p = .95). Similarly, cumulative ACE scores did not significantly correlate with working memory measured pre-stress (r = -.01, p = .96) or post-stress (r = -.07, p = .57), nor was violence significantly correlated with working memory pre-stress (r = -.02, p = .88) and post-stress (r = -.11, p = .36).

3.3 Discussion

The first aim of Experiment 2 was to replicate the findings of Experiment 1 regarding the relationship of inhibition in non-emotional and emotional contexts to childhood trauma and violent behavior. As will be discussed below, the replication attempt was successful.

Second, and more importantly, we sought to establish whether these relationships are aggravated by acute social stress. Independent of participant grouping, stress increased both Stroop effects in general. This finding demonstrates that the stress induction procedure worked as expected and can be considered a manipulation check for the effectiveness of the TSST-G. However, stress did not affect the relationships between ACEs or violent behavior with any measured non-emotional function. The color Stroop effects were not modulated by stress, nor was the larger congruency effect for high ACE participants increased by stress.

However, emotional Stroop effects were affected by stress. In Experiment 1, we found that responses to smile trials are better predictors of violent behavior compared to frown ones. Interestingly, in Experiment 2, the stress manipulation confirmed the special status of emotion regulation for smile responses in violent behavior. That is, the correlation of the overall facial Stroop effect with violence was significant only in the post-stress condition. In the categorical analysis, the interaction of Congruency and Violence was significantly modulated by stress, specifically due to an increase of the facial Stroop effect for smiles but not frowns.

Together, the results of Experiment 2 replicated Experiment 1 in a separate sample. Additionally, combined correlation analyses for Stroop effects for participants with complete data from Experiment 1 and the pre-stress condition of Experiment 2 (N=96) were correlated with cumulative *violence scores*. Results (r = .20, p = .06) confirmed that violence was not significantly correlated with Stroop effects for the colour Stroop task, even for a larger sample with more power. Thus, our findings showed that emotional inhibition, and more so under stressful conditions, explicitly affects the relationship between emotion regulation and violent behavior, especially so, among victims of ACEs.

4. General Discussion

The present study addressed two overarching questions, (1) the relationship of different forms of cognitive processes to childhood trauma and violent behavior and (2) the modulation of these relations by experimentally induced stress. The first question was investigated in Experiment 1 and replicated in Experiment 2, while the second question was studied in the second experiment only.

Similar to Experiment 1, participants were male students of county boarding schools from modest to poor socio-economic backgrounds. In Sample 1, 64.2 % of participants had experienced at least three childhood adverse events, compared to 48.4 % in the positively selected second sample.

4.1 ACE but not violence are related to non-emotional inhibition

In both experiments, we found a significant relationship between the color Stroop effect with ACE but not violence. ACE scores equal to or greater than four have been shown to pose an increased risk of poor health outcomes (e.g., 24). Accordingly, we categorized participants based on these criteria into two groups with high and low ACEs. The categorical analysis in both experiments showed that individuals with four or more traumatic events in childhood showed reduced inhibitory control, that is, larger Stroop effects. According to the separate ANOVA of the interference and facilitation components, the deficit of high ACE participants might be attributed to the interference component, indicating that the ability of participants to subdue distracting information is diminished by ACEs (65). However, one should treat this conclusion cautiously, as this difference between interference and facilitation was significant only in Experiment 1 but was only a trend in Experiment 2.

Together, the color word Stroop task indicated inhibitory control decrements to the degree that an individual experienced adversity in childhood. Such findings are in line with earlier studies showing that childhood trauma might result in deficient inhibition control (e.g., 3). Additionally, Stroop effects, as reviewed by van der Bij et al. (3), are likely to be increased in individuals that had been exposed to trauma early in life. Even among healthy participants, emotional neglect and physical abuse have been shown to be correlated with decreased cognitive control, as well as deficits in executive functioning in adulthood (31). These findings are in line with previous studies (e.g., 13) and strongly suggest that accumulated ACEs impair cognitive functions in non-emotional conditions. The findings that inhibition under non-emotional conditions are not correlated with violence may indicate that colour Stroop reflects a (partially) different kind of inhibition that is less related to self and affect regulation. However, whereas the relationship between the non-emotional inhibition (colour Stroop) and violence is not significant, it is in the same (positive) direction as the relationship between emotional inhibition (facial expression Stroop) and violence, and may need more power to confirm current findings.

4.2 ACE and Violence are both related to deficits in emotion regulation.

Previous studies (e.g., 41) suggest that in affective contexts, people might not be able to control their impulses even if they can do so in emotionally neutral conditions. Therefore, besides the cognitive Stroop task, we used the facial Stroop task that assesses response inhibition in an emotional context and can be seen as tapping into emotion regulation. In the facial Stroop task, a verbal prompt to smile or frown was presented superimposed on an emotional face (38, 67). Congruency effects in this task may be explained by facial mimicry, a motor action resulting from the spontaneous imitation of the facial expressions of others (e.g., 75).

Although the color word Stroop and facial Stroop tasks share the property of having overlapping relevant and irrelevant information, they differ in their relationship to interpersonal emotion. Whereas the color word Stroop task is purely cognitive and non-emotional, the face Stroop task requires an emotional facial expression in response to a word designating an emotional expression (smile, frown), while a background face displays a facial expression (67). The possibility that the congruency effects in these tasks tap into different aspects of control (cognitive vs. emotional) is supported by the absence of correlations between the color Stroop effects and face Stroop effects in both experiments.

In both experiments, in the correlational analysis, higher ACE scores were accompanied by larger overall facial Stroop effects, that is, diminished emotion regulation. However, in the categorical analysis, we found an interaction between Congruency and ACE only in Experiment 2 but not in Experiment 1. Based on these variable effects, one should interpret these results cautiously. However, one might suggest that, in contrast to inhibition deficits that are more profound in people with multiple ACEs, emotion regulation might be severely and negatively affected even with fewer incidents of ACEs. Therefore, in line with Pechtel and Pizzagalli (7), our results indicate that deficits in the affective domain should be particularly attended to when interacting with individuals with ACEs.

Notably, the facial expression Stroop task, an emotion-related task, predicted violent offending among victims of childhood trauma in both studies, whereas the non-emotional color Stroop task did not. In Experiment 1, our findings indicate that the frequency of violent behavior did not significantly correlate with the non-emotional color Stroop effects. However, the degree of violent behavior was strongly correlated with the facial Stroop effects for smile responses but not frown responses. The higher sensitivity of smile responses relative to frowns may be attributed to the fact that smiles imply affiliative intent. That is, smiles are mimicked more readily since they are more acceptable and bear no personal costs, in contrast to frowns that are mimicked less as they may be associated with aggression and perceived as socially maladaptive behavior (76). Importantly, these results were replicated in Experiment 2. That is, using a different sample in Experiment 2, we replicated the increase of the facial Stroop for smile responses with violence in the categorical analysis. Therefore, these consistent and replicable findings indicate a critical link between childhood trauma and violence by deficits in emotion regulation.

The differences between inhibition and emotion regulation in predicting violent offending may be explained if one considers the findings of Botdorf et al. (41). Their results showed that risk-taking in a laboratory driving task could be predicted by an emotional but not a cognitive Stroop task. Similarly, adolescents with ACEs may be able to hold inappropriate impulses in check under non-emotional (cool) conditions, but their still developing emotional regulation systems may be compromised in affective contexts (77). In other words, the tendency of individuals towards violence may relate to their deficits in emotion regulation, tapped into by the facial emotion Stroop effects, but not cognitive inhibition, as measured by the color Stroop task.

4.3 ACE and violence are related to each other but not to working memory and intelligence

Confirming previous reports (10, 21), in both samples, we found positive correlations between self-reported ACE and violence. This replicates findings that childhood adversity is related to later violent behavior (25), with offender groups reporting four times more ACEs than non-offenders (21).

Further, our results show that fluid intelligence, as measured by the BEFKI, and WM, as measured by the n-back task, were not significantly associated with a history of childhood adversity. Similarly, participants who reported occasional violent behavior did not show any differences in fluid intelligence and working memory compared to those who showed normative violent behavior. Notably, in Experiment 2, we increased the difficulty of the working memory test (replacing the one-back with a two-back task) in order to rule out the possibility that the null results found in Experiment 1 were related to the ceiling effect (71). However, as before, neither working memory nor fluid intelligence was significantly correlated with ACEs or violent behavior. Although some previous studies (e.g., 31) found WM decrements among individuals with a history of childhood maltreatment, other studies failed to replicate these results (e.g., 32). These findings, together with our results, show that ACEs and violent behavior might not affect intelligence and EFs in general but are related to rather specific deficits in cognitive and especially emotional inhibition.

4.4 Modulatory effects of experimental stress

In the present experiment, we had expected that stress would enhance the relations between ACE and violence with measures of cognitive processes. Although we consistently found such associations and could also demonstrate that the stress manipulation worked, stress only enhanced the difference between low and high violence participants in their congruency effects in the facial Stroop task – specifically for smile responses. This result may relate to the specific sensitivity of individuals with high violent behavior in a situation where they are put into an affiliative situation by requiring them to smile. As reviewed in the introduction, previous studies on stress effects on executive functions have been inconsistent. For instance, even though stress is generally thought to impair executive functions (e.g., 44), it might benefit some aspects of cognition (45). The highly specific stress effects in the present study align with such inconsistencies. Possibly executive functions are modulated by stress only in some participants and specific situations.

Notably, Casey et al. (78) showed that performance in a task involving inhibition was relatively poor and selectively so in the context of an emotional facial expression (smile) relative to a neutral facial expression. Combined with findings that childhood trauma impairs cognitive functioning, such findings may explain the even further depletion of inhibitory control under an emotional context of the facial expression Stroop task and stress, unlike the non-emotional color Stroop task. Reduced ability to react to stress has been shown to be a vulnerability factor linking childhood trauma and psychological disorders (79).

Under stress, the facial expression Stroop task seemed to tap into emotion regulation ability deficiencies that did not appear with the color word Stroop task. Being a period of heightened hypothalamus-pituitary-adrenal (HPA) axis reactivity (9), adolescence presents changes that are sometimes externalized as heightened stress-induced hormonal responses, correlated with high impulsivity and cognitive deficiencies (11). Such responses might be exacerbated by stressful situations, more so among victims of trauma (80, 81). While there was a general increase in Stroop effects after stress, with higher increases in the violent group, for frown responses, the violent group had very low Stroop effects ($M_{\Delta} = 14.3$ ms) compared to normative offenders ($M_{\Delta} = 61.4$ ms) pre-stress. Furthermore, there was a very small difference between frown response Stroop effects pre and post stress for the non-violent group ($M_{\Delta} = 3.0$ ms) compared to the frown response Stroop effect differences pre and post stress in the violent group ($M_{\Delta} = 26.5$ ms), indicating a sort of resilience of frown responses. Such differences in how smiles and frowns differ in their sensitivity to interference have been shown in other studies. For example, Recio and colleagues (2022) found that compared to non-mothers, mothers of pre-linguistic infants showed comparable interference effects for smile responses, but not for frown responses when facing infant distractor faces, suggesting caregiving response or empathy as possible intervening variables in these differences. Katembu and others (2022) found that when adult participants are required to frown at infant faces, the outer brow raiser (AU2), an action unit that is not related a typical frown expression, was activated or deactivated, an indication of how uniquely frown responses, compared to smile responses, are interfered with under a given set of experimental conditions. Our findings therefore corroborate previous studies showing the unique ways in which experimental conditions interfere with smiles compared to frowns.

All together, the present findings show that on the one hand, ACEs are linked to violent behaviour and inhibitory control deficits, and on the other, violent behaviour is linked to deficient inhibitory control under emotional (hot) conditions, revealing a relationship between stress and deficits in emotion regulation. This indicates that under stressful situations, adolescent victims of childhood trauma are susceptible to maladaptive violent behavior.

4.5 Limitations and perspectives

The present study was impacted by a number of limitations that could be overcome in future research. Unfortunately, we were not able to carry out endocrinological tests such as cortisol analysis in order to ascertain the effectiveness of the TSST in inducing stress. Although the TSST has been shown in other studies to induce stress (e.g., 82), it would be reassuring to demonstrate such effects not only indirectly at the performance level as we did here.

Although the findings in the present experiments were illuminating in showing specific relation of the facial Stroop tasks with the amount of violent behavior, due to Covid-19 pandemic-related restrictions, we were confined to populations with relatively limited variance in violence. Future research could study adolescents confirmed and held as violent delinquents and compare them to a normative high-school population. The sensitivity of the face Stroop task to show relationships to violent offending in contrast to its absence for the color Stroop task makes this task or similar emotional conflict paradigms critical tools for further studies in the mechanisms underlying violence and other kinds of deviant conduct.

Finally, for the facial expression Stroop task, we utilized white faces as stimuli among African participants. Although the expressions of the faces employed are considered to be largely universal, it is conceivable that in the face Stroop task, the same versus other ethnicity is relevant. Hence, future studies could investigate any differences in using faces of different ethnicities and races.

4.6 Conclusions

In the present study, we confirmed that emotional and cognitive inhibitions are affected by ACE. Importantly, deficits in emotion regulation, but not in non-emotional inhibition, were predicted by violent behavior in adolescents. Interestingly, the negative impact of emotion regulation deficits on violent behavior was aggravated under stress, but specifically in the smile response condition. These results indicate the special vulnerability of individuals prone to violent behavior when their emotion regulation is called for and when they are placed in an affiliative social situation.

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Appendix

Table A1

Experiment 1 ANOVA for Accuracies across Congruent, Incongruent, and Neutral conditions for the SCWT and the facial expression Stroop tasks

ANOVA					
	Color word Stroop	***df***	***F***	***p***	***η2***
ACE	*Congruency*	*2,102*	*14.19***	*.00*	*.22*
	Congruency x ACE	*2,102*	*2.23*	*.11*	*.04*
VIOLENCE	*Congruency*	2,102	12.89**	.00	.20
	Congruency x Violence	2,102	1.42	.24	.03
	Facial Expression Stroop				
ACE	*Congruency*	*2,64*	*21.35***	*.00*	*.40*
	Congruency x ACE	*2,64*	*2.86*†	*.07*	*.08*
	Response	*1,32*	*4.33**	*.05*	*.12*
	Response x ACE	*1,32*	*3.76*†	*.06*	*.11*
	Congruency x Response	*2,64*	*2.97*†	*.06*	*.09*
	Congruency x Response x ACE	*2,64*	*0.56*	*.57*	*.02*
	#SMILE: Congruency	*2,64*	*9.40***	*.00*	*.23*
	#SMILE: Congruency x ACE	*2,64*	*1.27*	*.29*	*.04*
	#FROWN: Congruency	*2,64*	*19.1***	*.00*	*.37*
	#FROWN: Congruency x ACE	*2,64*	*2.64*	*.16*	*.08*
VIOLENCE	*Congruency*	*2,64*	*19.75***	*.00*	*.38*
	Congruency x Violence	*2,64*	*0.24*	*.79*	*.01*
	Response	*1,32*	*3.96*†	*.06*	*.11*
	Response x Violence	*1,32*	*0.75*	*.39*	*.02*
	Congruency x Response	*2,64*	*2.92*†	*.06*	*.08*
	Congruency x Response x Violence	*2,64*	*0.01*	*.99*	*.00*

$* p < .05$; $** p < .01$; $^{\dagger} p < .1$

Notes:

Post-hoc test;

Table A2

Experiment 2 ANOVA of accuracies in the SCWT and the facial expression Stroop tasks as a function of Congruency and Stress

ANOVA					
	Color word Stroop	*df*	*F*	*p*	*η2*
ACE	*Congruency*	*2,120*	*45.53***	*00*	*.43*
	Congruency x ACE	*2,120*	*4.02**	*.01*	*.06*
	Stress	*1,60*	*0.16*	*.69*	*.00*
	Stress x ACE	*1,60*	*1.09*	*.30*	*.02*
	Congruency x Stress	*2,120*	*0.58*	*.56*	*.01*

	Congruency x stress x ACE	*2,120*	*1.16*	*.32*	*.02*
	#Facilitation: Congruency	*1,60*	*22.68***	*.00*	*.27*
	#Facilitation: Congruency x ACE	*1,60*	*12.36*	*.00*	*.17*
	#Inhibition: Congruency	*1,60*	*37.58***	*.00*	*.39*
	#Inhibition: Congruency x ACE	*1,60*	*0.04*	*.84*	*.00*
Violence	*Congruency*	2,120	46.03**	.00	.43
	Congruency x Violence	2,120	1.86	.16	.03
	Stress	1,60	0.24	.62	.00
	Stress x Violence	1,60	0.28	.60	.00
	Congruency x Stress	2,120	0.78	.46	.13
	Congruency x Stress x Violence	2,120	1.05	.36	.02
Facial Expression Stroop					
ACE	*Congruency*	*2,120*	*71.40***	*.00*	*.54*
	Congruency x ACE	*2,120*	*6.15***	*.00*	*.09*
	Stress	*1,60*	*0.87*	*.37*	*.01*
	Stress x ACE	*1,60*	*3.07†*	*.09*	*.05*
	Response	*1,60*	*12.17***	*.00*	*.01*
	Response x ACE	*1,60*	*10.15***	*.00*	*.12*
	Congruency x Stress	*2,120*	*2.59†*	*.08*	*.04*
	Congruency x Stress x ACE	*2,120*	*0.28*	*.75*	*.01*
	Congruency x Response	*2,120*	*1.09*	*.34*	*.02*
	Congruency x Response x ACE	*2,120*	*4.60**	*.01*	*.07*
	Stress x Response	*1,60*	*1.61*	*.21*	*.03*
	Stress x Response x ACE	*1,60*	*0.88*	*.35*	*.01*
	Congruency x Stress x Response	*2,120*	*0.53*	*.59*	*.01*
	Congruency x Stress x Response x ACE	*2,120*	*0.42*	*.66*	*.01*
	#SMILES: Congruency	*2,120*	*37.70***	*.00*	*.39*
	#SMILES: Congruency x ACE	*2,120*	*10.89***	*.00*	*.15*
	#FROWNS: Congruency	*2,120*	*37.74***	*.00*	*.39*
	#FROWNS: Congruency x ACE	*2,120*	*1.26*	*.29*	*.02*
Violence	*Congruency*	*2,120*	*67.62***	*.00*	*.53*
	Congruency x Violence	*2,120*	*0.79*	*.46*	*.01*
	Response	*1,60*	*9.00***	*.00*	*13*
	Response x Violence	*1,60*	*1.11*	*.30*	*.02*
	Stress	*1,60*	*0.84*	*.36*	*.01*
	Stress x Violence	*2,64*	*0.26*	*.61*	*.00*
	Congruency x Response	*2,120*	*1.11*	*.36*	*.02*
	Congruency x Response x Violence	*2,120*	*0.30*	*.74*	*.01*
	Congruency x Stress	*2,120*	*2.83†*	*.06*	*.05*
	Congruency x Stress x Violence	*2,120*	*1.17*	*.32*	*.02*
	Response x Stress	*1,60*	*1.23*	*.27*	*.02*
	Response x Stress x Violence	*1,60*	*0.92*	*.34*	*.02*
	Congruency x Response x Stress	*2,120*	*0.66*	*.52*	*.01*
	Congruency x Response x Stress x Violence	*2,120*	*0.38*	*.69*	*.01*

** $p < .05$; ** $p < .01$*

Notes:

Post-hoc test;

For experiment 1, categorical analysis were used where correlations with ACE or violence were significant. A split ANOVA was carried out by dichotomizing these variables. With previous research showing that ACE scores equal or greater than four (≥ 4) pose an increased risk of poor health outcomes (e.g., 24), ACE was categorized as low if a participant scored ≤ 3 points and as high if ACE scores were ≥ 4, while violent behavior was categorized as normative, occasional, or frequent as described under the self-reported behavior checklist. However, the ANOVA results were included only in this appendix (Table A3) since our correlations using cumulative measures of ACE and violence for Experiment 1 were satisfactory under Experiment 1 conditions.

Table A3

Experiment 1. ANOVA results for group factors ACE and Violence with repeated measures on Congruency (congruent, incongruent, neutral) for the color word Stroop and the facial expression Stroop tasks

Group Factor	*Source*	***df***	***F***	***p***	***η2***
	Color word Stroop				
ACE	*Congruency (C)§*	*2, 102*	*155.54***	*.00*	*.75*
	C x ACE	*2,102*	*5.97***	*.00*	*.11*
	#Facilitation: C	*1,51*	*79.71***	*.00*	*.61*
	#Facilitation: C x ACE	*1,51*	*1.48*	*.23*	*.03*
	#Inhibition: C	*1,51*	*131.29***	*.00*	*.72*
	#Inhibition: C x ACE	*1,51*	*7.59**	*.03*	*.13*
Violence	*C*	2,102	139.17**	.00	.73
	C x Violence (V)	2,102	1.31	.27	.03
	Facial Expression Stroop				
ACE	*C*	*2,64*	*34.28***	*.00*	*.52*
	C x ACE	*2,64*	*2.17*	*.12*	*.06*
	Response (R)	*1,32*	*16.05***	*.00*	*.33*
	R x ACE	*1,32*	*.16*	*.70*	*.01*
	C x R	*2,64*	*3.11**	*.05*	*.37*
	C x R x ACE	*2,64*	*.05*	*.95*	*.00*
	#SMILE: C	*2,64*	*17.86***	*.00*	*.36*
	#SMILE: C x ACE	*2,64*	*1.18*	*.31*	*.04*
	#FROWN: C	*2,64*	*21.49***	*.00*	*.40*
	#FROWN: C x ACE	*2,64*	*1.08*	*.35*	*.03*
Violence	*C*	*2,64*	*35.20***	*.00*	*.52*
	C x V	*2,64*	*3.08**	*.05*	*.09*
	R	*1,32*	*16.18***	*.00*	*.34*
	R x V	*1,32*	*0.41*	*.52*	*.01*
	C x R	*2,64*	*3.33**	*.04*	*.09*
	C x R x V	*2,64*	*2.36*	*.10*	*.07*
	#SMILES: C	*2,64*	*19.28***	*.00*	*.38*
	#SMILES: C x V	*2,64*	*3.81†*	*.06*	*.11*
	#FROWNS: C	*2,64*	*21.47***	*.00*	*.40*
	#FROWNS: C x V	*2,64*	*1.06*	*.35*	*.03*

* $p < .05$; ** $p < .01$; † $p < .1$

Notes:

Post-hoc test;

§ The *F*-values for the same within-subject test, e.g. Congruency, may slightly vary when the particiapnts are dichotomized according to ACE and violence scores into groups of different sizes because the error variance then slightly differs.

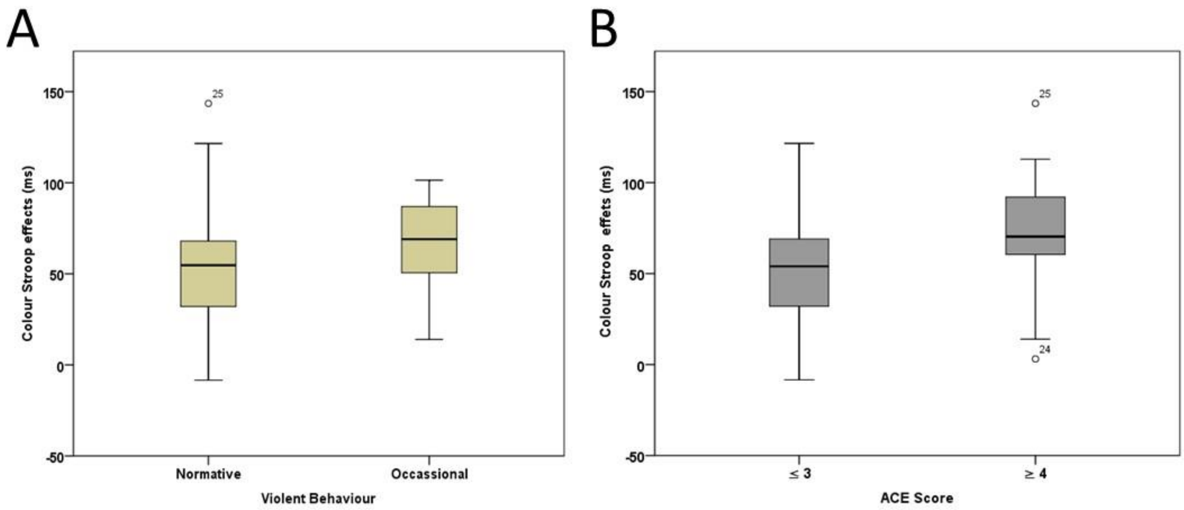

Figure A3 Boxplots for the color word Stroop effects (incongruent minus congruent), separated for the Group factors (A)*ACE* and (B) *violence*.

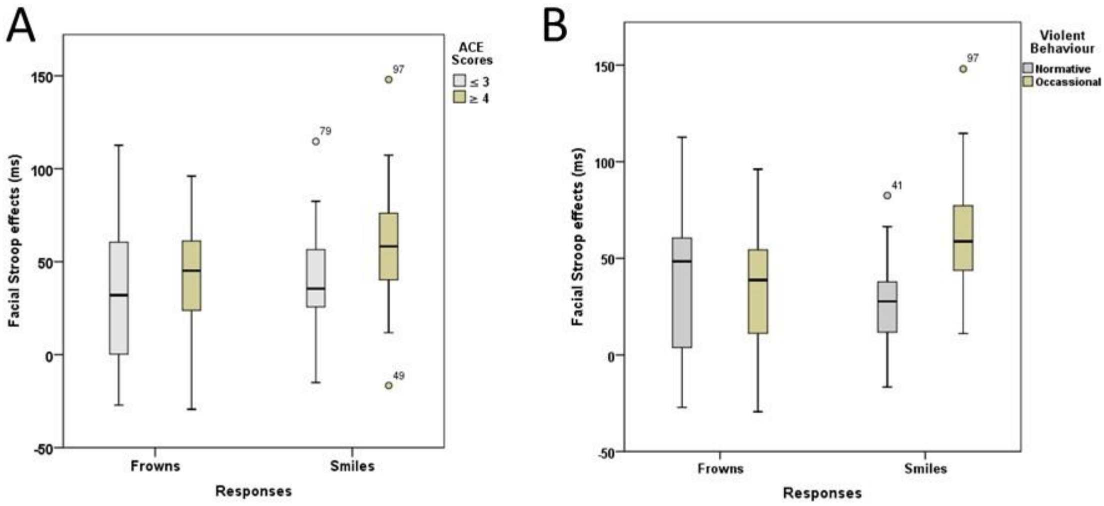

Figure A4 Boxplots of the Face Stroop effects for the group factors (A) *ACE* and (B) *violence*.