Title: A high-density EEG investigation into the neurocognitive mechanisms underlying differences between personality profiles in social information processing.

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Key words: Response inhibition, interference resolution, action withholding, social cognition, personality, action orientation.

Abstract

This study investigated whether differences between personality styles in the processing of social stimuli reflect variability in underlying general-purpose or social-specific neurocognitive mechanisms. Sixty-five individuals classified previously into two distinct personality profiles underwent high-density electroencephalography whilst performing tasks that tap into both aspects of cognitive processing – namely, two distinct facets of general-purpose response inhibition (interference resolution and action withholding) during social information processing. To determine the stage of processing at which personality differences manifest, we assessed event-related components associated with the early visual discrimination of social stimuli (N170, N190) and later more general conflict-related processes (N2, P3). Although a performance index of interference resolution was comparable between the personality profiles, differences were detected in action withholding. Specifically, individuals expressing a wider repertoire of personality styles and more adaptive emotion regulation performed significantly better at withholding inappropriate actions to neutral faces presented in emotional contexts compared with those exhibiting stronger preferences for fewer and less adaptive personality styles and more ruminative affective tendencies. At the neurophysiological level, however, difference between the profiles was observed in brain responses elicited to the same stimuli within the N170. These results indicate that neural processes related to early visual discrimination might contribute to differences in the suppression of inappropriate responses towards social stimuli in populations with different personality dispositions.

1. Introduction

Interacting successfully with other individuals requires us to infer their mental (e.g., motivational) and emotional state, and adapt our own behaviour in a contextually appropriate manner. Given the breadth and complexity of these social cognitive processes, it is perhaps unsurprising to see immense variability in interpersonal behaviour among the general population. In an earlier study, we revealed that personality can have both direct *and* indirect influences on various facets of social cognition, which might underpin differences in social behaviour (1): compared to individuals reporting an adaptive approach to emotion regulation, those with more ruminative tendencies reported weaker cognitive empathy and, indirectly through the heightened negative affective states they experience, less affective empathy when perceiving the emotions of others. Originally, we interpreted these opposing patterns of social information processing to reflect differences in self-other distinction – a social-specific cognitive process that affords the flexible prioritisation of self- or other-representations. More recently, however, scholars have begun to question whether such differences in social cognition reflect inter-individual variability in more domain-general mechanisms; namely, those involved in cognitive control (2–4) that together support the prioritisation of relevant and suppression of irrelevant information, and the inhibition or cancellation of inappropriate actions. Cognitive control might allow us to switch flexibly between competing self- and other-representations by preventing us from misattributing our egocentric perspective on the world onto others (5). The present study therefore investigated this alternative interpretation of our former findings: Do the differences we observed previously between two discrete personality profiles reflect variability in general-purpose cognitive control rather than social-specific aspects of cognition?

In our previous study, personality was defined according to the Personality Systems Interaction theory (PSI; e.g., (5)). In this theoretical framework, characteristic behavioural patterns across various contexts (i.e. personality styles) are driven by primary affective dispositions (i.e. sensitivity to positive and negative affect) and preferences for certain cognitive processing modes (i.e. analytical versus intuitive). Personality styles represent non-pathological analogues of personality disorders defined by DSM-IV or ICD-10 (6), and personality disorders emerge when an individual fails to regulate their primary affective responses and preferences for a certain personality style become persistent across differing contexts (e.g., Loyal-Dependent, Optimistic-Rhapsodic). This context-specific and flexible ability of self-regulation is also conceptualised dimensionally – from action to state orientation. Action-oriented individuals are efficient in disengaging from affective states in order to address the task or goal at hand, while those who are predominantly state-oriented typically remain in a ruminative and hesitant mode when faced with difficulties, adversities or failures. Applying Latent Profile Analysis (7) to data acquired from in a large non-clinical sample with an instrument borne out of PSI theory, we revealed two dissociable personality profiles that exhibited contrasting social cognitive and affective dispositions (1). The first, which we labelled Flexible given its primary characteristics (2), comprised individuals characterised by a relatively large repertoire of personality styles and reported more adaptive (action-oriented) emotion regulation tendencies. In contrast, those in a second Analytical profile reported a strong preference for fewer personality styles characterised by heightened sensitivity for negative affect (e.g., Self-critical–Avoidant, Passive–Depressive) and reported a tendency towards more ruminative (state-orientated) emotion regulation. Individuals classified as Flexible demonstrated superior social cognitive abilities even at a very basic level (1): they expressed more control over their imitative tendencies and, through a heightened sensitivity to bodily signals (i.e., interoceptive awareness), better suppression of emotionally driven behaviours relative to those in the Analytical profile. The Analytic profile exhibited more state negativity, reported higher distress when empathising with others, and were less able to reconcile discrepancies between their own and others' perspective in a visual perspective-taking task compared with their Flexible counterparts.

Previously, we interpreted these differences in social cognition between the personality profiles to reflect biases in their processing of social information specifically. It is entirely conceivable that such differences in social information processing are just one instantiation of domain-general executive processes, however, such as those comprising cognitive control. Cognitive control refers broadly to the ability to regulate automatic behaviour that is inappropriate within the current situational context (8), thereby enabling behaviour that is adaptive to changing task demands and goals. Although various taxonomies of cognitive control exist, models differentiate typically among updating (monitoring and updating of working memory representations), shifting (switching flexibly between multiple tasks and/or mental sets), and response inhibition (the intentional overriding of a dominant or pre-potent response (see (9–11)). Response inhibition is conceptualised as a multidimensional construct that has been delineated further into three discrete sub-processes that follow in temporal succession (12): interference resolution (the cognitive selection of relevant and suppression of irrelevant information), action withholding (inhibition of a prepared, but not yet initiated action), and action cancellation (stopping an ongoing action; (9,13)). Differences in response inhibition between the two personality profiles would manifest particularly within social contexts that require a high degree of self-regulation to supress socially inappropriate behaviour (14).

One example is imitation (15): Humans exhibit an involuntary tendency to mimic the behaviour of their interaction partners. Although this appears to serve important social functions, for instance increasing rapport and affiliation with other individuals (16), such mimicry will be inappropriate and require suppression in certain social contexts (e.g., among competitors, during interaction with out-groups members, or in zero-acquaintance contexts; (17). This is illustrated by behaviour on stimulus-response compatibility (SRC) tasks; when individuals are required to execute simple actions in response to symbolic imperative stimuli (e.g., coloured dots), they are faster and more accurate when they observe simultaneously another person performing the same (compatible) compared to a different (incompatible) action (18,19). Since the observed action is irrelevant to the task at hand, a larger compatibility effect is used to index poorer interference resolution during social information processing. Similarly, social interactions are characterised by the demand for mutual co-adaptation – interactants must continuously attempt to infer the intentional and motivational states of their interaction partner(s) and modify their own behaviour accordingly. This will often involve suppressing behaviours that we might otherwise express because they become contextually inappropriate. Such action withholding is often investigated with the Go/No-go (GNG) task, whereby a pre-potent motor response induced to frequent ("Go") stimuli must be supressed to infrequent ("No-go") stimuli. Poor action withholding is indexed by incorrect responding to No-go stimuli. Interestingly, inter-individual variability in both interference resolution and action withholding indexed with these tasks has been associated with stable personality dispositions, such as those related to cognitive style, anxiety, narcissism or rumination (20–25). Studies that have examined the interplay between these components of response inhibition and social information processing are relatively scarce, however, and none have investigated this directly at the neurophysiological level (3,26,27).

The neural events supporting the inhibition of imitative tendencies (28,29) and the suppression of inappropriate actions (30) have been investigated with electroencephalography (EEG). This has revealed several components of event-related potentials (ERPs) associated with these discrete cognitive processes; both low-level perceptual processes related to the early detection of body parts – the N170 and N190 components (29,31–34), and later N2 and P3 components implicated in higher-level processes of conflict detection and resolution (30,35). The N170 and N190 are measured, respectively, at 130-200 and 150-200 ms after stimulus onset at lateral parieto-occipital (31,32) and occipito-temporal sites (4,36). The N2 component is recorded at 200-400 ms post-stimulus at fronto-central electrodes (29,30), while the P3 component occurs 300-500 ms after stimulus onset at fronto-central or parietal sites (dependent upon the paradigm employed (37), and has been associated specifically with action monitoring and response suppression (4,38). Importantly, both the N2 and P3 appear to be more responsive to social aspects of stimuli, such as in- relative to out-group effects (29), and emotional compared with non-emotional facial expressions (30,39). To the best of our knowledge, however, no studies have investigated if and how the neural underpinnings of interference resolution and action withholding might differ between groups defined by contrasting personality profiles and patterns of social information processing.

In this study, we examined the role of response inhibition and its neurocognitive processes associated with differences between personality profiles in processing of hand movements and facial emotional expressions: The SRC task was employed to measure interference resolution, and an emotional GNG task (eGNG) assessed action withholding. These tasks were administered to a subset of individuals classified previously as Flexible or Analytical. To capture the neural events associated with each component of response inhibition, and compare them between the two profiles, we capitalised on the superior temporal resolution offered by high-density EEG. This setup thus allowed us to identify the conditions and time points during which neurophysiological differences occur between the two personality groups. Given the apparent importance of response inhibition in social information processing (2,40,41), and our own previous findings (1), we expected more interference (increased task-irrelevant imitation) and poorer action withholding (higher number of false alarms) in Analytical compared with Flexible individuals. Furthermore, in line with existing evidence showing increased neural processing associated with response inhibition in populations sensitive to negative affect (22,42), we predicted that this inferior performance of individuals classified into the Analytical profile would be reflected in heightened neural responding specific to processing stages subserving conflict processing and resolution rather than social information processing. For this reason, we hypothesised that the groups would differ on the N2 and P3 ERP components associated with response inhibition, but not on the N170 and N190 components that index the early perceptual stage of social information processing.

2. Methods

2.1. Participants

The sample consisted of 65 students and associates of a local university (26 males; M_{age} = 22.8 years, SD = 3.3), who were re-recruited from a sample tested one year earlier (M = 12.7 months, SD = 3.5) with an extensive battery of tasks measuring social cognition (1). In this original sample, 29 participants were categorised into Flexible personality profile and 36 to Analytical profile using Latent Profile Analysis on scores of 14 personality dimensions from Personality Styles and Disorders Inventory (Reserved-Schizoid, Charming-Histrionic, Assertive-Antisocial, Critical-Negativistic, Wilful-Paranoid, Optimistic-Rhapsodic, Ambitious-Narcissistic, Loyal-Dependent, Spontaneous-Borderline, Unselfish-Self-Sacrificing, Passive-Depressive, Intuitive-Schizotypal, Reserved-Schizoid, Self-critical-Avoidant; (6). Importantly, in contrast to the “extreme group approach”, this data-driven analytical technique classified participants into groups by identifying qualitatively distinct configurations of variables. The two resulting groups did not differ significantly in age ($M_{FLEXIBLE}$ = 24.1, SD = 3.7; $M_{ANALYTICAL}$ = 24.1, SD = 3.2; $t(63) = .097$, $p = .923$), sex ($Males_{FLEXIBLE}$ = 14, $Males_{ANALYTICAL}$ = 12; $\chi^2[1, N = 65] = 1.494$, $p = .222$), or completed education level ($\chi^2[3, N = 65] = 1.279$, $p = .734$). No participants reported any history of neurological or psychiatric diagnosis, and all had normal to corrected-to-normal vision. All participants were right handed, as assessed with the revised version of the Edinburgh Handedness Inventory (43). The laterality quotient (LQ) was calculated as (right-left)/(right+left) x 100, and the average LQ was 99.5 (SD = 4.0). The study was approved by the local Ethics Board. Written informed consent was acquired from all participants prior to taking part in the study. Participants received approx. €20 for their time.

2.2. *Materials*

The procedure consisted of an eGNG and an SRC tasks presented in a fixed order. Since both tasks involved protocols identical to those reported in our previous study, readers are referred to the earlier paper for more detailed descriptions (1) and we describe only the most crucial aspects of the design below.

2.2.1. Stimulus-Response Compatibility Task

On the SRC task (44), the participants were instructed to execute finger-lifting movements signalled by a coloured dot (the imperative stimulus), while simultaneously observing task-irrelevant matching (compatible) or opposing (incompatible) finger movements. The task comprised four trial types – Compatible (COM), Incompatible (INCOM), Catch, and Baseline. Trials started with all the fingers of the stimulus hand resting on a flat surface, signalling that participants should depress two keys on a response box with their index and middle fingers. After a variable period, the imperative stimulus was superimposed over the stimulus hand to indicate the action required from the participant (i.e. index or middle finger lifting). At that point, the stimulus hand either remained still (Baseline), made a movement without an accompanying imperative stimulus (Catch), or made the same (COM) or different movement signalled by the imperative stimulus (INCOM; see Figure 1 A). In a randomised sequence, each trial type was presented 30 times within each of the four blocks. Each block presented one of four different stimulus hands: an actor's right or left hand rotated clockwise (LEFT+90, RIGHT+90) or counter-clockwise (LEFT-90, RIGHT-90) from the participants' perspective. As we have since shown that only the right stimulus hand presented counter-clockwise isolates imitative from confounding spatial compatibility effects (45), we only consider data acquired during the RIGHT-90 block herein. Note that Catch trials were included in the paradigm only to ensure that participants paid attention throughout the task. Since neither Catch nor Baseline trials require interference resolution processing, they were not considered in the following analyses. To align with past research, we focused on the difference in reaction time (RT) and accuracy for compatible relative to incompatible trials (INCOM-COM; (18,46)). Higher and lower values of this difference measure in RT and accuracy, respectively, indicate more involuntary imitation of the task-irrelevant stimulus and, therefore, poorer interference resolution. For RT, this difference score was calculated using only correct responses within 3 standard deviations of individual's overall mean.

2.2.2. Emotional Go/No-go paradigm

The eGNG task was designed according to (47), comprising six blocks of 40 trials. Each trial started with the presentation of a fixation cross, followed by a face with an emotional or neutral expression (see Figure 1 B). At the beginning of each block, participants were instructed to press the space bar as quickly as possible whenever a specific expression was presented. These Go trials occurred frequently (70%; n = 28) to elicit a strong tendency to respond. In contrast, No-go trials were presented infrequently (30%; n = 12), during which participants were instructed to withhold any response. On each block, one of three emotional expressions (angry, fearful, and happy) served either as the Go or No-go stimulus, and neutral expressions served as the other trial type. This created the following 6 blocks, presented in a counterbalanced manner: Angry (Go)–neutral (No-go), and neutral (Go)–angry (No-go); fearful–neutral and neutral–fearful; happy–neutral and neutral–happy. In each block, the order of Go and No-go trials was pseudo-randomised to ensure that no two No-go trials occurred in succession. Prior to the task, participants performed a short practice block with a different stimulus set to that employed in the experimental blocks. We used stimuli from the Radboud Faces Database (14 males; (48), grey scaled and cropped to remove any hair. As a measure of action withholding performance in response to socially relevant stimuli, we compared the false alarm rate between our profiles – that is, the proportion of incorrect relative to correct responses on emotional and neutral No-go trials (NGE, NGN). Following the approach taken by (47), accuracy in the two trial types was adjusted (0% = .01 and 100% = 99) and then z-scored using the sample standard deviation. Higher values on these measures represent poorer action withholding.

2.2.3. EEG acquisition

Both experimental tasks were administered using E-prime 2.0.10.356 (Psychology Software Tools, Pittsburgh, PA, USA) and presented via an external projector. Testing was conducted in a dimly lit and soundproofed room with electromagnetic shielding. Participants were seated comfortably 160 cm from the screen (visual angle: 58°) and instructed to minimise head movements during the tasks. EEG was recorded with a 256 channel EGI system GES400, with Cz as the reference electrode. The sampling frequency was 1 kHz.

2.2.4. EEG pre-processing

To minimise any influence of muscle artifacts, the dataset was reduced to 204 electrodes by removing sensors positioned on the face and neck. Data were then band-pass filtered using Fast Fourier Transform of 1 – 40 Hz. Independent component analysis was conducted to identify and suppress eye-blinking, muscle movement and cardiac artifacts, and poorly performing electrodes were interpolated by a spherical spline. Next, the data were re-referenced to the average and inspected visually, and any residual artifacts were discarded from further analysis. The data from three participants were omitted from the SRC dataset due to excessive artifacts throughout the entire task. Only correct trials were considered in subsequent EEG analyses. Across the sample, this resulted in the removal of 7% of trials for the SRC task and 10% of trials from the eGNG task. Importantly, the profiles did not differ significantly with respect to the average number of trials discarded due to incorrect responding and/or artifact rejection in either task: On average, 1.6 trials (Flexible profile) relative to 2.6 trials (Analytical profile) per participant were removed from the SRC dataset (p = .152), while 2.8 (Flexible) compared with 3.9 trials per participant were excluded from the eGNG task (p = .114). The entire data pre-processing was performed by combining routines under the EEGLAB toolbox, with in-house solutions running under MATLAB 2017a. Trial segmentation involved a 300 ms pre-stimulus baseline and 800 ms post-stimulus window.

2.2.5. EEG analysis

Signals were averaged across electrodes in clusters characterising each ERP component. The temporal windows were pre-defined according to prior research on the selected components and stable peak amplitudes recorded across task conditions (i.e., INCOM-COM, NGE, and NGN) and profiles. Given the sensitivity of the N190 to human body parts and the N170 to faces specifically, we interrogated the former for the SRC task and the latter for the eGNG. These two early negative components were defined as follows: The N190 was measured 150-200 ms post-stimulus and recorded from lateral occipito-temporal electrodes (P1, P3, P5, PO7, 98, 99; and P2, P4, P6, 141, 152, PO8; (36,49)), while the N170 was measured 130-200 ms after stimulus onset and recorded from a cluster of lateral parieto-occipital electrodes (PO7, P7, P9, O1, 98, 107, 108, 114, 115; and PO8, P8, P10, O2, 151, 152, 159, 160, 168; (31,32)). For the SRC task, the N2 was recorded within a 240-300 ms post-stimulus window across electrodes 8, 9, 186, C1, C2, and Cz (29,30); and for the eGNG task, it was recorded 200-300 ms post-stimulus across electrodes FCz, Cz, 7, 8, 9, 16, 17, 186, and 198. In line with prior research (29,34,37), the P3 in the SRC task was measured 280-380 ms post-stimulus over the following parieto-occipital electrodes: Pz, POz, Oz, 117, 118, 127, 139, PO3, and PO4. For the eGNG task, the P3 was computed 420-500 ms post-stimulus from more anterior sites: FCz, Cz, 7, 8, 9, 16, 17, 186, and 198. An illustration of the topographies and electrode clusters across conditions for each task is presented in Figure 2.

Mean amplitudes pooled across electrodes in the respective clusters were calculated for each condition of the two tasks and each profile. Differences between the two personality profiles in interference resolution (SRC task; INCOM – COM) and action withholding (eGNG task; NGE, NGN) were analysed using the exact same statistical approach applied to the behavioural data. All statistical analyses were performed in SPSS 27.

3. Results

3.1. Behaviour

The performance of individuals comprising the Flexible and Analytical profile was compared separately for each task. Profile comparisons were performed using an independent-samples t-test or, for variables that violated the assumption of normality, a non-parametric Mann-Whitney test. This revealed that, although participants in the Flexible group appeared to exhibit better interference resolution on the SRC task in RT (M = 4.30 ms, SE = 6.17) compared to their Analytical counterparts (M = 9.12 ms, SE = 6.35), which converges with previous findings, these differences were not significant ($t_{(63)}$ = -.536, p =

.594). Similarly, accuracy indices from SRC task were comparable for the two groups ($M_{FLEXIBLE}$ = -.34 %; SE = .48, $M_{ANALYTICAL}$ = .00 %, SE = .79; $t_{(63)}$ = -.35, *p* = .725). In contrast, Flexible participants displayed significantly less false alarms (M = -.15, SE = .12) relative to those classified as Analytical across NGN trials (M = .12, SE = .13; *U* = 352.5, *p* = .023; *r* = .28, 95% CI [-.53, -.04]), indicating superior action withholding. This is illustrated in Figure 3A. Interestingly, however, no such differences between the two groups were observed across NGE trials (*p* = .529).

3.2. EEG

Mirroring the behavioural results, no significant differences between the profiles emerged for amplitudes in any of the investigated ERP components related to interference processing (N190: *U* = 382.0, *p* = .184; N2: *U* = 370.0, *p* = .134; P3: *U* = 439.0, *p* = .601). Similarly, amplitudes of the ERP components associated with action withholding were also comparable for both profiles (NGN: $p \leq .126$; NGE: $p \leq .154$; see Figure S1); with the exception of the NGN condition; specifically, we observed significantly reduced amplitudes in Flexible (M = - .38 μV, SE = .21) relative to Analytical individuals (M = -.91 μV, SE = .16) during action suppression for the N170 component (*U* = 355.0, *p* = .027, *r* = .27, 95% CI [-.52, -.03]; see Figure 3B).

4. Discussion

This study investigated whether dissociable patterns of social information processing observed previously between two personality profiles are underpinned by differences in response inhibition, and if this is reflected in neural processes associated with this facet of cognitive control. To achieve this aim, we compared behavioural performance and associated neurophysiological responses between individuals categorised previously as Flexible or Analytical on two tasks believed to engage sub-processes of response inhibition. The Flexible personality profile comprises individuals who use various personality styles and report more adaptive, action-oriented (goal-directed) emotion regulation, whereas the Analytical profile is characterised by a strong tendency to employ fewer personality styles (e.g., Self-critical-Avoidant, Passive-Depressive) and report state-oriented emotion regulation (ruminative tendencies in the face of adversity). We compared these two groups specifically on the first two stages of response inhibition: the selection of relevant and inhibition of irrelevant information (interference resolution), and the inhibition of prepared but not yet initiated action (action withholding). We predicted that the Analytical profile would show poorer interference resolution and action withholding compared with the Flexible group, together with an increased neural responding in the N2 and P3 ERP components that index conflict processing and resolution. Processing of socially relevant stimuli was expected to be similar in the early perceptual stage (N170 and N190 ERP components). Contrary to these expectations, both performance and electrophysiological indices of interference resolution, operationalised as the ability to suppress imitation of irrelevant finger movements, were comparable in the two groups. However, relative to individuals classified as Flexible, those in the Analytical group demonstrated inferior action withholding in an emotional Go/No-go task and stronger brain responses in the N170 ERP component, which is believed to support rapid visual discrimination of facial expressions. We discuss these findings related to each of the two sub-processes in the temporal sequence in which they occur.

At first glance, the lack of significant difference in performance on the SRC task between our profiles, suggestive of comparable interference resolution, appears to diverge from our earlier findings. Previously, we observed *significantly* poorer interference control in individuals classified as Analytical relative to those expressing the Flexible profile (1). This might reflect the instability of the Flexible and Analytical profiles into which we classified our participants in the current study; since this classification was carried out approximately one year prior to the current study, it could be argued that the same group allocation might have become inappropriate as a result of personality alterations occurring in the meantime. However, personality types resembling our profiles (i.e. Resilient and Overcontrolled) express high consistency across adolescence and young adulthood (50,51). Moreover, action- or state-orientation dispositions remain highly stable over the course of several years (52). An alternative interpretation that we consider much more likely is that this discrepancy reflects important differences between the study designs. Due to the between-subject stimulus presentation we employed in our earlier study, only half of the original sample responded to the right stimulus hand oriented counter-clockwise that we focused on here (RIGHT-90) – the other half observed a left hand oriented clockwise (LEFT+90). Since we have shown more recently that the latter stimulus elicits both imitative- and spatial-compatibility effects (45), we re-inspected these prior results to determine whether responses differed to each of these stimulus hands. Indeed, while the RIGHT-90 stimulus elicited a positive compatibility effect (M = 28.35 [± 2.99] ms), this was reversed for the LEFT+90 (M = -9.17 [± 3.19] ms) – that is, responses were facilitated by imitatively *incompatible* actions produced by this latter stimulus. Such counter-imitation indicates the strong influence of confounding spatial effects (see also (53)). It is entirely possible, therefore, that spatial rather than imitative stimulus-response associations were behind our previous observation of differences between the personality profiles on the SRC task. This interpretation would converge with a recent finding that inter-individual differences in the SRC task are restricted to spatial compatibility effects (3).

The Flexible and Analytical profiles were indistinguishable in their ability to suppress pre-potent action towards emotional facial expressions in the context of less salient, neutral face stimuli. However, individuals comprising the Flexible profile were significantly better at suppressing their responses to neutral faces in the context of emotional facial expressions when compared with the Analytical profile. This difference might have resulted from particular characteristics of the employed paradigm. Previous research on cognitive control that compares similar subsamples (i.e. action- and state-oriented individuals) has shown that differences in this ability are subtle and condition-specific. For instance, significantly poorer conflict adaptation in state- compared with action-oriented individuals diminishes relatively quickly with task practice (54), and appears to be specific to high-demand paradigms with infrequent incompatible trials (55). It is proposed that this reflects a distinction between initiating and maintaining cognitive control: while cognitive control must be *re-initiated* in tasks where conflict trials are rare (thus requiring more cognitive recourses), cognitive control only needs to be *maintained* when conflict-inducing trials are more frequent (55). Poorer performance of state-oriented individuals might thus reflect difficulties in maintaining mental representations of task instructions in working memory, or insufficient attention to the task (55,56). Second, individuals with higher levels of anxiety or depression tend to perceive neutral (ambiguous) social stimuli as negative (57), and this tendency has been shown to be relatively inflexible (58). Due to their sensitivity to negative affect, Analytical individuals might therefore have been affected by frequent emotional facial expressions in Go trials (the majority of which were negatively valenced) more than those in the Flexible group, such that differentiating neutral from the prevailing emotional faces might have required more cognitive resources (59). This interpretation is consistent with the significantly greater N170 amplitudes we have observed in Analytical relative to Flexible individuals in response to neutral No-go trials, suggestive of more effortful visual discrimination of non-emotional faces in a predominantly salient context. This interpretation is supported by stronger brain responses observed in conflict-related tasks in populations reporting higher levels of anxiety and neuroticism (59,60). Surprisingly, this neural sensitivity does not result in more successful performance and has been interpreted as a “hidden cost” of maintaining performance efficiency at the standard level (42). We speculate that attentional resources that should have been allocated to withholding a response to low-arousal stimuli have already been depleted from discriminating neutral from emotional faces in No-go trials in Analytical individuals (30).Taken together, our results might reflect methodological aspects of the eGNG task as a measure of action withholding – specifically, the motivational relevance of the stimulus material and the unequal ratio of trials requiring action relative to those requiring action-suppression. On the other hand, any influence of task characteristics likely interacted with the predisposition of individuals from Analytical profile to be affected by a prevailing salient context and their inflexibility in perceiving neutral social stimuli negatively.

All these interpretations require further investigation. Although abnormalities in the N170 are taken as an index of the disturbances to social functioning that characterise many disorders (28), very little is known about how this processing stage differs between personality types in non-clinical populations on tasks similar to ours in which early visual processing is a prerequisite for subsequent response inhibition. Some earlier evidence indicates that there are no differences in the N170 with respect to trait anxiety (22,56) or shyness (57), but fundamental differences in study design prevent meaningful comparisons with the present findings. Most notably, emotional facial expressions were either used to provide feedback on responses to Go trials (22), presented in a passive viewing condition (57) or as part of an explicit categorisation task (56).

It is important to mention that our results are in need of replication due to the relatively small sizes of the compared groups. The effects we have observed are of medium size in the context of psychological and individual differences research (61), however, so we are confident they provide a good starting point for future investigations. Furthermore, the present findings open up exciting avenues for further research: Since our EEG analyses focused only on correct responses and stimulus- rather than response-locked ERPs, differences in personality characteristics related to error-related processing (e.g., error-related negativity; (62)) and response execution (pre-motion positivity or readiness potential; (28,29)) should be examined. Previous studies with clinical populations indicate that such line of research might unveil the neural mechanisms specific to interference resolution and action withholding in social contexts (56). For instance, errors are known to be processed as more salient in individuals with anxiety disorders (62), and individuals with autism spectrum disorder appear to differ from neurotypical populations in response preparation when performing social interference tasks (28). Finally, intra-individual variability was not considered in our analyses. This analytic perspective has the potential to provide further insight and/or possibly alternative explanations for the relationships among response inhibition, social cognition, and personality factors. Future studies are encouraged to employ statistical techniques that take this aspect into account.

Conclusions

In the present study, we revealed performance differences in action withholding between individuals expressing differing patterns of personality styles and propensities for action- or state-orientation. Contrary to our initial predictions, this behavioural difference does not appear to be underpinned by domain-general neurocognitive mechanisms associated with response inhibition. Instead, electrophysiological recordings indicate that differing action withholding performance reflects increased processing during the early perceptual stage of visual discrimination of (and, possibly, attention to) emotionally salient and neutral social stimuli. Individuals categorised as Analytical were less able than those classified as Flexible to suppress a prepared action when it required distinguishing between neutral from prevailing emotional (but task-irrelevant) social stimuli. Further, this appears to be accompanied by more effortful neural processing in the N170 component. Our results provide important insights into personality differences in discrete processing stages during response inhibition to social stimuli at both the behavioural and neurophysiological levels. These findings align with previous research, which suggests that individuals within Analytical personality profile can become overwhelmed more easily when faced with stressful social situations, especially when they are required to perform novel and demanding tasks.

References

1.
2. Binney RJ, Ramsey R. Social Semantics: The role of conceptual knowledge and cognitive control in a neurobiological model of the social brain. Neurosci Biobehav Rev. 2020;112(January):28–38.
3. Darda KM, Butler EE, Ramsey R. Individual differences in social and non-social cognitive control. Cognition. 2020;202(October 2019).
4. Rauchbauer B, Lorenz C, Lamm C, Pfabigan DM. Interplay of self-other distinction and cognitive control mechanisms in a social automatic imitation task: An ERP study. Cogn Affect Behav Neurosci. 2021;
5. Kuhl J. A theory of self-development: Affective fixation and the STAR model of personality disorders and related styles. In: Heckhausen J, editor. Advances in psychology, 131 Motivational psychology of human development: Developing motivation and motivating development. New York: Elsevier Science; 2000. p. 187–211.
6. Kuhl J, Kazén M. PSSI—Inventář stylů osobnosti a poruch osobnosti. Praha: Testcentrum; 2002.
7. Williams GA, Kibowski F. Latent class analysis and latent profile analysis. In: Jason L, Glenwick D, editors. Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods. New York: Oxford University Press; 2016. p. 143–51.
8. Gratton G, Cooper P, Fabiani M, Carter CS, Karayanidis F. Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. Psychophysiology. 2018;55(3):1–29.
9. Diamond A. Executive functions. Annu Rev Psychol. 2013;64:135–68.
10. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. Cogn Psychol. 2000;41(1):49–100.
11. Miyake A, Friedman NP. The nature and organization of individual differences in executive functions: Four general conclusions. Curr Dir Psychol Sci. 2012;21(1):8–14.
12. Sebastian A, Pohl MF, Klöppel S, Feige B, Lange T, Stahl C, et al. Disentangling common and specific neural subprocesses of response inhibition. Neuroimage [Internet]. 2013;64(1):601–15. Available from: http://dx.doi.org/10.1016/j.neuroimage.2012.09.020
13. Zhang R, Geng X, Lee TMC. Large-scale functional neural network correlates of response inhibition: an fMRI meta-analysis. Brain Struct Funct. 2017;222(9):3973–90.
14. Hippel W Von, Gonsalkorale K. Is Bloody Revolting !" Inhibitory Control of Thoughts Better Left Unsaid. 2005;16(7):497–500.
15. Cross KA, Salvatore T, Losin EAR, Iacoboni M. Controlling automatic imitative tendencies: Interactions between mirror neuron and cognitive control systems. Neuroimage. 2013;83:493–504.
16. Chartrand T, Lakin J. Using Nonconscious Behavioral Mimicry to Create Affiliation and Rapporte. Psychol Sci. 2003;14(4):334–9.
17. Leander NP, Chartrand TL, Bargh JA. You Give Me the Chills: Embodied Reactions to Inappropriate Amounts of Behavioral Mimicry. Psychol Sci [Internet]. 2012;23(7):772–9. Available from: https://doi.org/10.1177/0956797611434535
18. Cracco E, Bardi L, Desmet C, Genschow O, Rigoni D, Coster L De, et al. Automatic imitation: A meta-analysis. Psychol Bull. 2018;144(5):453–500.
19. Heyes C. Automatic Imitation. Psychol Bull. 2011;137(3):463–83.
20. Hogeveen J, Obhi SS. Automatic imitation is automatic, but less so for narcissists. Exp Brain Res. 2013;224(4):613–21.
21. Obhi SS, Hogeveen J, Giacomin M, Jordan CH. Automatic imitation is reduced in narcissists. J Exp Psychol Hum Percept Perform. 2014;40(3):920–8.
22. Sehlmeyer C, Konrad C, Zwitserlood P, Arolt V, Falkenstein M, Beste C. ERP indices for response inhibition are related to anxiety-related personality traits. Neuropsychologia. 2010;48(9):2488–95.
23. Senderecka M, Szewczyk J, Wichary S, Kossowska M. Individual differences in decisiveness:

ERP correlates of response inhibition and error monitoring. Psychophysiology. 2018;55(10):1–19.

24. Hsieh S, Yu Y, Chen E, Yang C, Wang C. Personality and Individual Di ff erences ERP correlates of a fl anker task with varying levels of analytic-holistic cognitive style. Pers Individ Dif [Internet]. 2020;153(1):109673. Available from: https://doi.org/10.1016/j.paid.2019.109673
25. Aarts K, Pourtois G. Anxiety disrupts the evaluative component of performance monitoring: An ERP study. Neuropsychologia [Internet]. 2012;50(7):1286–96. Available from: http://dx.doi.org/10.1016/j.neuropsychologia.2012.02.012
26. Butler EE, Ward R, Ramsey R. Investigating the relationship between stable personality characteristics and automatic imitation. PLoS One [Internet]. 2015;10(6):1–18. Available from: http://dx.doi.org/10.1371/journal.pone.0129651
27. Colzato LS, Steenbergen L, Hommel B. Rumination impairs the control of stimulus-induced retrieval of irrelevant information, but not attention, control, or response selection in general. Psychol Res [Internet]. 2020;84(1):204–16. Available from: http://dx.doi.org/10.1007/s00426-018-0986-7
28. Deschrijver E, Wiersema JR, Brass M. Disentangling Neural Sources of the Motor Interference Effect in High Functioning Autism: An EEG-Study. J Autism Dev Disord. 2017;47(3):690–700.
29. Rauchbauer B, Pfabigan DM, Lamm C. Event-related potentials of automatic imitation are modulated by ethnicity during stimulus processing, but not during motor execution. Sci Rep. 2018;8(1):1–15.
30. Albert J, López-Martín S, Carretié L. Emotional context modulates response inhibition: Neural and behavioral data. Neuroimage [Internet]. 2010;49(1):914–21. Available from: http://dx.doi.org/10.1016/j.neuroimage.2009.08.045
31. Feuerriegel D, Churches O, Hofmann J, Keage HAD. The N170 and face perception in psychiatric and neurological disorders: A systematic review. Clin Neurophysiol [Internet]. 2015;126(6):1141–58. Available from: http://dx.doi.org/10.1016/j.clinph.2014.09.015
32. Hinojosa JA, Mercado F, Carretié L. N170 sensitivity to facial expression: A meta-analysis. Neurosci Biobehav Rev [Internet]. 2015;55:498–509. Available from: http://dx.doi.org/10.1016/j.neubiorev.2015.06.002
33. Schindler S, Bublatzky F. Attention and emotion: An integrative review of emotional face processing as a function of attention. Cortex [Internet]. 2020;130:362–86. Available from: https://doi.org/10.1016/j.cortex.2020.06.010
34. Deschrijver E, Wiersema JR, Brass M. The influence of action observation on action execution: Dissociating the contribution of action on perception, perception on action, and resolving conflict. Cogn Affect Behav Neurosci [Internet]. 2017;17(2):381–93. Available from: http://dx.doi.org/10.3758/s13415-016-0485-5
35. Albert J, López-Martín S, Tapia M, Montoya D, Carretié L. The role of the anterior cingulate cortex in emotional response inhibition. Hum Brain Mapp. 2012;33(9):2147–60.
36. Thierry G, Pegna AJ, Dodds C, Roberts M, Basan S, Downing P. An event-related potential component sensitive to images of the human body. Neuroimage. 2006;32(2):871–9.
37. Polich J. Updating P300: An integrative theory of P3a and P3b. Clin Neurophysiol. 2007;118(10):2128–48.
38. Enriquez-Geppert S, Konrad C, Pantev C, Huster RJ. Conflict and inhibition differentially affect the N200/P300 complex in a combined go/nogo and stop-signal task. Neuroimage [Internet]. 2010;51(2):877–87. Available from: http://dx.doi.org/10.1016/j.neuroimage.2010.02.043
39. Zhang W, Lu J. Time course of automatic emotion regulation during a facial Go/Nogo task. Biol Psychol [Internet]. 2012;89(2):444–9. Available from: http://dx.doi.org/10.1016/j.biopsycho.2011.12.011
40. Darda KM, Ramsey R. The inhibition of automatic imitation: A meta-analysis and synthesis of fMRI studies. Neuroimage [Internet]. 2019;197(April):320–9. Available from: https://doi.org/10.1016/j.neuroimage.2019.04.059
41. Nash K, Schiller B, Gianotti LRR, Baumgartner T, Knoch D. Electrophysiological indices of

response inhibition in a Go/NoGo task predict self-control in a social context. PLoS One. 2013;8(11).

42. Berggren N, Derakshan N. Attentional control deficits in trait anxiety: Why you see them and why you don't. Biol Psychol [Internet]. 2013;92(3):440–6. Available from: http://dx.doi.org/10.1016/j.biopsycho.2012.03.007
43. Milenkovic S, Dragovic M. Modification of the Edinburgh Handedness Inventory: A replication study. Laterality. 2013;18(3):340–8.
44. Brass M, Bekkering H, Wohlschläger A, Prinz W. Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. Brain Cogn. 2000;44(2):124–43.
45.
46. Catmur C, Heyes C. Time course analyses confirm independence of automatic imitation and spatial compatibility effects. J Exp Psychol Hum Percept Perform [Internet]. 2011;37(2):409–21. Available from: http://eprints.ucl.ac.uk/19456/
47. Tottenham N, Hare TA, Casey BJ. Behavioral assessment of emotion discrimination, emotion regulation, and cognitive control in childhood, adolescence, and adulthood. Front Psychol. 2011;2(MAR):1–9.
48. Langner O, Dotsch R, Bijlstra G, Wigboldus DHJ, Hawk ST, van Knippenberg A. Presentation and validation of the radboud faces database. Cogn Emot. 2010;24(8):1377–88.
49. Deschrijver E, Wiersema JR, Brass M. Disentangling Neural Sources of the Motor Interference Effect in High Functioning Autism: An EEG-Study. J Autism Dev Disord. 2017;47(3):690–700.
50. Meeus W, Van de Schoot R, Klimstra T, Branje S. Personality Types in Adolescence: Change and Stability and Links With Adjustment and Relationships: A Five-Wave Longitudinal Study. Dev Psychol. 2011;47(4):1181–95.
51. Specht J, Luhmann BM, Geiser C. On the consistency of personality types across adulthood: Latent profile analyses in two large-scale panel studies. J Pers Soc Psychol. 2014;107(3):540–56.
52. Bettschart M, Wolf BM, Herrmann M, Brandstätter V. Age-related development of self-regulation: Evidence on stability and change in action orientation. J Res Pers [Internet]. 2021;91:104063. Available from: https://doi.org/10.1016/j.jrp.2020.104063
53. Boyer TW, Longo MR, Bertenthal BI. Is automatic imitation a specialized form of stimulus-response compatibility? Dissociating imitative and spatial compatibilities. Acta Psychol (Amst). 2012;139(3):440–8.
54. Fischer R, Plessow F, Dreisbach G, Goschke T. Individual Differences in the Context-Dependent Recruitment of Cognitive Control: Evidence From Action Versus State Orientation. J Pers. 2015;83(5):575–83.
55. Jostmann NB, Koole SL. On the Regulation of Cognitive Control: Action Orientation Moderates the Impact of High Demands in Stroop Interference Tasks. J Exp Psychol Gen. 2007;136(4):593–609.
56. Inzlicht M, Bartholow BD, Hirsh JB. Emotional foundations of cognitive control. Trends Cogn Sci [Internet]. 2015;19(3):126–32. Available from: http://dx.doi.org/10.1016/j.tics.2015.01.004
57. Hirsch CR, Meeten F, Krahé C, Reeder C. Resolving Ambiguity in Emotional Disorders: The Nature and Role of Interpretation Biases. Annu Rev Clin Psychol. 2016;12:281–305.
58. Everaert J, Bronstein M V., Cannon TD, Joormann J. Looking Through Tinted Glasses: Depression and Social Anxiety Are Related to Both Interpretation Biases and Inflexible Negative Interpretations. Clin Psychol Sci. 2018;6(4):517–28.
59. Kungl MT, Rutherford HJV, Heinisch C, Beckmann MW, Fasching PA, Spangler G. Does anxiety impact the neural processing of child faces in mothers of school-aged children? An ERP study using an emotional Go/NoGo task. Soc Neurosci [Internet]. 2020;15(5):530–43. Available from: https://doi.org/10.1080/17470919.2020.1788988
60. Wieser MJ, Brosch T. Faces in context: A review and systematization of contextual influences on affective face processing. Front Psychol. 2012;3(NOV):1–13.
61. Funder DC, Ozer DJ. Evaluating Effect Size in Psychological Research: Sense and Nonsense. Adv Methods Pract Psychol Sci. 2019;2(2):156–68.

62. Meyer A. Developing Psychiatric Biomarkers: a Review Focusing on the Error-Related Negativity as a Biomarker for Anxiety. Curr Treat Options Psychiatry [Internet]. 2016;3(4):356–64. Available from: http://dx.doi.org/10.1007/s40501-016-0094-5

Figure 1. Experimental stimuli and procedures. *A*: Schematic of the trial sequence for the Stimulus-response compatibility (SRC) task. An inter-trial-interval (ITI) was followed by a warning stimulus presented randomly for 800, 1600 or 2400 ms, which was then replaced with an image depicting the end-point of a finger-lifting action. Superimposed onto this image was a coloured dot, which served as the imperative stimulus and defined the condition (Compatible [COM; *left*], Baseline [BASE; *middle*] or Incompatible [INCOM; *right*]). To isolate imitative- from confounding orthogonal-compatibility effects, we examined behavioural and neurophysiological responses to only the right stimulus hand presented in counter-clockwise rotation. *B*: Schematic of the trial sequence on the emotional Go/No-go (eGNG) task. Each trial started with the presentation of a fixation cross (ITI; 1000-2000 ms, presented randomly), followed by a face with an emotional or neutral expression presented for 500 ms.

Figure 2. Topographical maps across interrogated task conditions of N190, N2, and P3 windows for the SRC task (*left*) and N170, N2, and P3 windows for the eGNG task (*right*) with electrode clusters selected for analysis.

Figure 3. Behavioural and electrophysiological responses. *A*: Behavioural differences between the profiles, showing the group-specific Compatibility effect ([INCOM-COM], expressed in seconds; *left*) and false alarm rate for neutral No-go trials (expressed as z-scores; *right*). *B*: Amplitudes for Compatibility effect in the N190 (*top left*) and No-go neutral condition in the N170 window (*top right*) and ERP waveforms for all conditions in the SRC (*bottom left*) and eGNG task (*bottom right*) for Flexible (*blue*) and Analytical (*red*) individuals. *Abbreviations*: COM = compatible, INCOM = Incompatible, NGE = No-go emotional, NGN = No-go neutral condition; * = $p < .05$.