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Response Inhibition in the Parametric Go/No-Go Task and its Relation to Impulsivity and Subclinical Psychopathy

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Abstract

The current study utilises the parametric Go/No-go task (PGNG), a task that examines changes in inhibitory performance as executive function load increases, to examine the link between psychopathic traits, impulsivity and response inhibition in a cohort of healthy participants. The results show that as executive function load increased, inhibitory ability decreased. High scores on the Cognitive Complexity subscale of the Barratt Impulsivity Scale (BIS-11) predict poor inhibitory ability in the PGNG. Similarly, high scores on the Psychopathy Personality Inventory-Revised (PPI-R) Blame Externalization subscale predict response inhibition deficits in the PGNG, which loads more on the executive functions than the standard Go/No-go task. The remaining BIS-11 as well as PPI-R subscales did not interact with inhibitory performance in the PGNG highlighting the specificity of associations between aspects of personality and impulsivity with inhibitory performance as cognitive load is increased. These data point towards the sensitivity of the PGNG in studying response inhibition in the context of highly impulsive populations and its utility as a measure of impulsivity.

Response Inhibition in the Parametric Go/No-Go Task and its Relation to Impulsivity and Subclinical Psychopathy

The ability to flexibly adapt one's behaviour to fulfil the demands of both long-term goals and the requirements of the environment is a crucial skill. For example, if a banknote is blown across the street the automatic impulse might be to chase it, but this automatic behaviour needs to be modified dependent on the current level of risk associated with allowing that impulse, e.g. collision with traffic or crowd, and potential detrimental effects to other current goals. The importance of this cost-reward contingent adaptation of our impulses is reflected in the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5; APA, 2013; DeYoung, 2010), where the failure to regulate these impulses is the second most common symptom and a key diagnostic feature of several psychiatric disorders, e.g. attention deficit/hyperactivity disorder (ADHD; APA, 2013), bipolar disorder (APA, 2013; Najt et al., 2007) and psychopathy (Hare, 1991; Hare, 2003).

Given the complexity of controlling impulsive behaviour in the context of goal maintenance and risk avoidance, there is considerable interest in determining what factors give rise to, and regulate, impulsive behaviour. A recent meta-analysis by Sharma and colleagues (Sharma, Markon, & Clark, 2013) demonstrated several personality-based factors associated with self-report measures of impulsivity: Extraversion/positive emotionality, neuroticism/negative emotionality and disinhibition, and a further set of cognitive 'behavioural impulsivity' factors: Inattention, inhibition, impulsive decision-making and shifting. Of note, the relationship between self-reported and experimental measures of impulsivity in the study of Sharma et al. (2013) were lower than expected, possibly indicating that the traditional laboratory measures of impulsivity rely on measuring response inhibition in isolation, ignoring the interplay between executive functions, which is required to emulate impulsive behaviour outside the experimental context (Miyake et al., 2000). Importantly, despite a low relationship between self-reported and laboratory impulsivity tasks, inhibitory ability is featured by Sharma and colleagues (2013) as a factor in both experimental tasks and self-reports and is the focus of the current study.

Barkley (1997) describes behavioural inhibition/inhibitory ability in terms of three related processes: the inhibition of prepotent responses, the interruption of on-going responses, and inhibition of processes/information interfering with on-going responding. Common experimental assessments of response inhibition have been developed in order to measure these three aspects of inhibition separately. For example the ability to inhibit interfering information is commonly assessed using Stroop (Stroop, 1935) and Flanker (Eriksen & Eriksen, 1974) tasks; the inhibition of pre-potent responding by the Go/No-go task; and the capacity to inhibit on-going responding is commonly assessed using the Stop Signal task (Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984; Schachar & Logan, 1990). Several reports have demonstrated how poor performance on these tasks is related to individual differences in self-report measures of impulsivity, consistent with the finding of Sharma et al., (2013), that reduced inhibitory ability is a key aspect of the multifaceted construct of impulsivity (Keilp, Sackheim, & Mann, 2005; Reynolds, Ortengren, Richards, & de Wit, 2006; Spinella, 2004). For example, in the Go/No-go task, failure to inhibit No-go trials, trials on which the normal requirement to respond has to be inhibited, has been positively correlated to a classical self-report measure of impulsivity (Barratt Impulsivity Scale, BIS-11; Patton, Stanford, & Barratt, 1995;

Keilp et al., 2005; Spinella, 2004). Specifically the ability to withhold a prepotent response has been shown to correlate with constituent factors relating to a reduced ability to focus, associated with the Attentional factor, and to inhibit actions, associated with the Motor Impulsiveness factor (Keilp et al., 2005; Spinella, 2004). Similarly, using a more complex version of the Go/No-go task and investigating the relationship between performance and the BIS-11 subscales that constitute the Attentional, Motor and Nonplanning factors, Reynolds and colleagues (2006) found a positive relation between the amount of commission errors on No-go trials and the Cognitive Complexity subscale of the BIS-11, reflecting reduced inhibitory ability for subjects who are too impulsive for pursuing mentally challenging activities.

Outside the laboratory setting, performance on inhibition tasks has been found to correlate with problematic impulsive behaviour such as gambling, substance use, aggression and safety-related risk taking (Clark, Cornelius, Kirisci, & Tarter, 2005; Foster, Hillbrand, & Silverstein, 1993; Giancola, Mezzich, & Tarter, 1998; Kirisci, Tarter, Mezzich, & Vanyukov, 2007; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Nigg, et al., 2006). Similarly a number of mental health disorders that have as part of their pathology an increased level of impulsivity also show impaired performance on inhibition tasks (Alderson, Rapport, & Kofler, 2007; Gruber, Rathgeber, Braeunig, & Gauggel, 2007; King, Colla, Brass, Heuser, & von Cramon, 2007; Mullane, Corkum, Klein, & McLaughlin, 2009; Najt et al., 2005; Vaurio, Simmonds, & Mostofsky, 2009), strengthening the proposition that heightened impulsivity is linked to deficits in inhibition.

However, despite a number of positive findings demonstrating a link between cognitive measures of inhibition and conditions associated with impaired impulse control (e.g. Alderson et al., 2007; Losier, McGrath, & Klein, 1996; Strakowski et al.,

2010) the relationship is inconsistent. One example is found in psychopathy, a disorder characterised by a demonstrable lack of inhibitory control and impulsive behaviour (Hare, 1991; Hart & Dempster, 1997). The theoretical prediction, based on the difficulties people with psychopathic characteristics have in regard to inhibiting socially inappropriate behaviour, would be that they should perform badly on experimental inhibition tasks. While research into psychopathy focuses primarily on criminal populations, psychopathy is currently seen as a dimensional construct (Edens, Marcus, Lilienfeld, & Poythress, 2006; Walters, et al., 2007) and research using non-criminal populations can inform the likely relationships between impulsivity and inhibition in criminal populations. In non-criminal populations, psychopathy is most often assessed using the Psychopathic Personality Inventory-Revised (PPI-R; Lilienfeld & Andrews, 1996; Lilienfeld & Widows, 2005). To date, research using the PPI-R in conjunction with the standard version of the Go/No-go task is sparse, but has failed to show an influence of psychopathy on inhibitory ability (Carlson & Thai, 2010; Kim & Jung, 2014). For example, Kim and Jung (2014) recently reported neural differences using a Go/No-go task in students scoring high on the PPI-R, but failed to find any associated behavioural differences. Carlson and Thai (2010) employed an alternative inhibition task, the Continuous Performance Task (CPT), which incorporates a stronger demand on sustained attention and the need to apply continuous rule-updates. Differences in neural activity were found between high and low scoring participants on the PPI-R factor Fearless Dominance, although no corresponding behavioural effect was found on measures of response inhibition.

Attempts to address the relationship between psychopathy and inhibitory ability, as measured via self-reported impulsivity levels were similarly inconclusive (Berg, Hecht, Latzman, & Lilienfeld, 2015; Morgan, Gray, & Snowden, 2011). While

Morgan and colleagues (2011) reported positive associations between the PPI-R Impulsive Antisociality factor and the BIS-11 total score, as well as its three higher-order factors of impulsivity relating to Attentional, Motor and Nonplanning impulsivity, a second investigation reported an unexpected negative correlation between the BIS-11 total score and the PPI-R Impulsive Antisociality factor and a positive correlation with the PPI-R Fearless Dominance factor (Berg et al., 2015).

Given impulsive behaviour is a key part of the psychopathic construct in both subclinical and forensic populations (Hare, 1991; Hare, 2003; Hart & Dempster, 1997; Lilienfeld & Andrews, 1996; Lilienfeld & Widows, 2005) and the aforementioned link between inhibitory ability and impulsivity (Keilp et al., 2005; Reynolds et al., 2006; Sharma et al., 2013; Spinella, 2004), we propose that one reason for a failure to identify a clear link between the psychopathy construct and inhibition is a result of the way response inhibition is often tested. Tasks such as the standard Go/No-go task attempt to measure response inhibition in isolation of other cognitive components, however recent evidence suggests that this may ignore important contributions from other cognitive functions. Inhibitory ability is postulated to be one of the main components of the brain's executive function (EF) system (Baddeley & Logie, 1999; Conway & Engle, 1994; Miyake et al., 2000) and while the specific nature and number of functions that comprise the EF system is still a matter of debate, the term EF is more an umbrella term for several high level cognitive processes that control behaviour, all the currently proposed EFs share the characteristic of being neurophysiological 'frontal brain systems' (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Cognitive functions that have been labelled as being part of the EF system include information updating, mental set-shifting, inhibition of prepotent responses, goal maintenance, working memory and planning

(Baddeley & Hitch, 1974; Engle & Kane, 2004; McCabe et al., 2010; Miyake et al., 2000; Smith & Jonides, 1999) [1]. Of relevance to the current study, Miyake et al. (2000) used an individual differences design to demonstrate that the three proposed executive functions of information updating, mental set-shifting and inhibitory ability are predominantly non-unitary in nature, but there does exist a modest correlation between them suggesting a level of shared resource. Miyake et al. (2000) proposed two potential sources for the underlying commonality; a central capacity constituting controlled attention and an underlying inhibitory requirement common across the three executive functions of information updating, mental set-shifting and inhibitory ability. In other words, the model of the unity and diversity of executive functions proposes that although these three executive functions can be assessed independently, they draw resources from the same underlying capacity and thus loading on one of these executive functions necessarily reduces the available resources for the other two executive functions. Based on these findings it was suggested that the relationship between EFs should be taken into account when studying each executive component separately, for example when studying inhibitory ability (Miyake et al., 2000). Furthermore, Friedman and colleagues (2008) extended the findings of Miyake et al. (2000) by demonstrating that the genetic contribution to executive functioning is extremely high and could explain nearly all variance in individual differences in EF. With regard to the diversity of executive functions, little unique variance could attributed to a separable inhibition function; rather individual differences in inhibitory performance were explained by a common EF factor. There was, however, unique variance that could be attributed to both set-shifting and memory updating functions. Given the high inter-relatedness of the executive functions it can be argued that previous research into inhibitory functioning and psychopathy may have yielded inconclusive/inconsistent results due to shifts in processing strategy, or additional allocation from central shared EF system resource, as the inhibitory system was put under strain.

A more recent variant of the Go/No-go paradigm has been developed that takes all three executive functions postulated by Miyake and colleagues (2000) into consideration, thereby addressing the issues of shared capacity across functions and the contexts in which response inhibition takes place. The parametric Go/No-go task (PGNG; Langenecker, Zubieta, Young, Akil, & Nielson, 2007a) shares many similarities with the standard Go/No-go task but comprises three difficulty levels with each level involving a different number of EF components, namely set-shifting and information updating, alongside a requirement to inhibit a prepotent response. Whereas the first level involves building a prepotent response to target letters, the second and third level of the PGNG involve continuous information updating as well as a strong demand on set-shifting ability to successfully determine the appropriate stimulus to inhibit. The inclusion of these additional loads taxes the underlying shared EF resource, such as that proposed by Miyake et al. (2001), which leads to impaired response inhibition at higher task levels. The result of this is that the commonly seen ceiling effects in the standard Go/No-Go task (Langenecker et al., 2007a; Plewnia et al., 2013) are removed which allows for better differentiation between individuals.

Previous research on the validity of the PGNG has found strong test-retest reliability as well as validity (Langenecker et al., 2007a). Critically and in accordance with the view that response inhibition should be considered alongside other executive functions, inhibitory ability in the PGNG is significantly related to complex measures of executive functions. A previous report has shown that performance in the Stroop Colour-Word Test, Digit-Span as well as Digit-Symbol Tasks, the Trail Making Test version B, and perseverance errors in the Wisconsin Card Sorting Test is related to PGNG performance and indicate its association with executive functions associated with response interference, working memory capacity and set shifting (Langenecker et al., 2007a). Furthermore, the application of the PGNG to a variety of patient populations has found it to be sensitive to individual differences (Giel et al., 2012; Langenecker et al., 2005; Langenecker et al., 2007b; Langenecker, Briceno, Harnid, & Nielson, 2007c; Weisenbach et al., 2012; Wong, Mahar, Titchener, & Freeman, 2013), where the standard Go/No-go task has failed to do so, despite strong a priori expectations of response inhibition deficits in the patient groups. For example, earlier applications of the standard Go/No-go task to patients with bipolar disorder, a mental disorder strongly associated with impulsive behaviours, showed no relation between bipolar illness and response inhibition (Alsthuler et al., 2005; Elliott et al., 2004; Kaladjian et al., 2009a; Kaladjian et al., 2009b; Strakowski et al., 2008; Welander-Vatn et al., 2009; Wessa et al., 2007), but the more sensitive PGNG revealed response inhibition deficits associated with state as well as trait characteristics of bipolar patients (Langenecker, Saunders, Kade, Ransom, & McInnis, 2010; Ryan et al., 2012). Due to this high sensitivity of the PGNG and its design taking the inter-relatedness of executive functions into account, this task might be a valuable tool to determine the relationship between psychopathy and impulsivity as measured by response inhibition in non-criminal populations.

In sum, a wealth of research into the link between inhibitory performance, psychopathy and impulsivity has proven to be inconsistent, with some suggesting that the relative simplicity of the standard Go/No-go task makes examining individual differences in prepotent responding difficult (Langenecker et al., 2007a; Votruba &

Langenecker, 2013). It is therefore of considerable theoretical and practical importance to assess how inhibitory performance is affected by impulsivity and psychopathic tendencies in a task that is designed to circumvent the problems of ceiling effects and simplicity of the standard Go/No-go task and also takes into account the interaction of the inhibition system with other executive functions. The current investigation therefore tested a cohort of healthy participants on the PGNG while also collecting psychometric information relating to their levels of impulsivity and psychopathy.

Method

Participants

Data from eighty-six [2] psychology students (30 males) with normal or corrected-to-normal vision is reported. Participants (age *M* = 22.99, *SD* = 5.15, ranging from 18 to 38 years) were reimbursed for participation with £5 or credits as part of their degree. The experiment was approved by the Ethics Committee of Swansea University and all participants provided informed consent before taking part in the experiment. Participants were screened for aberrant responses and neither skippers not faders, according to the declaration of Votruba and Langenecker (2013), appear to be present in the current dataset.

Task Design

Stimuli were the twelve letters of the alphabet from O to Z, shown in capitals in white font on a black background. From a distance of approximately 60 cm, the stimuli subtended a horizontal visual angle of .71 degrees and a vertical visual angle of .88 degrees. The experiment was programmed using Matlab R2010b

(Mathworks Inc., Massachusetts, USA) and the Psychtoolbox package (Brainard, 1997; Kleiner et al, 2007; Pelli, 1997). All stimuli were presented centrally on an 18" Monitor, running at a resolution of 1280 x 1024; keyboard responses were obtained from a standard USB keyboard.

The parametric Go/No-go Task was adapted from Langenecker et al. (2007a). Participants viewed a stream of letter stimuli onscreen, monitoring for target stimuli which changed depending on the level of the experiment. Each letter was presented for 500 ms, interleaved by a jittered inter-stimulus interval (ranging from 500 ms to 1500 ms in steps of 50 ms) during which a fixation cross was displayed in the centre of the screen. In the first stage of the PGNG, a prepotent response was acquired by requiring participants to press a button with their dominant index finger as soon as they detected any of the target letters X, Y or Z and to ignore all other letters. The second phase of the PGNG introduced an inhibitory component (percentage correctly inhibited trials; PCIT) by asking the participants to only respond to the target letters if the previous target letter was not the identical (i.e. respond to X following Y, but not X following X), ignoring any of the lure letters that were presented in between (non-alternation rule). Here, only the target letters X and Y were presented in addition to the lure letters. The third phase measured response selection (percentage correct target trials; PCTT) in addition to inhibition under higher task demands by using the same non-alternation rule as in level two, but now all three target letters are presented. The order of completion of levels two and three of the PGNG was counterbalanced across participants to account for confounding effects such as task practice and fatigue.

The first stage consisted of 180 trials of which 25% required a Go response, in the second and third stage 360 trials were presented each, of which 20% were Go trials and 5% were No-go trials. At each level, the presentation of the letter stimuli was pseudo-randomized, having the restriction to show one to five lure letters in between target letters. Additionally, all target letters were presented equally often per level and Go and No-go trials.

Dependent measures of the PGNG include: Go reaction times relating to processing speed, PCTT (Percentage Accuracy for Go trials), PCIT (Percentage Accuracy for No-go trials), the efficiency ratio of the PGNG, a measure that describes the balance between reaction time on Go trials with accuracy, (((3*PCTT + PCIT) / 4) / mean reaction time)*100, and the coefficient of variation, indicating the dispersion of reaction times (standard deviation/ reaction time)*100. The latter two measures of the PGNG, the efficiency ratio as well as the coefficient of variation, are especially useful in patient research and are reported here for comparison purposes. Similarly, the efficiency ratio in the PGNG has the potential of detecting specific response styles, e.g. a more conservative response style is reflected in high accuracy scores, but low processing speed, leading to low efficiency scores (Votruba & Langenecker, 2013). The coefficient of variation is a widely used measure of response variability and has high clinical relevance, for example high response variability has been proposed as an early marker for Alzheimer’s disease (Duchek et al., 2009) and is a consistent characteristic of impulsivity-related disorders such as bipolar (Mattis, Papolos, Luck, Cockerham, & Thode, 2011; Patino et al., 2013) and Attention Deficit/Hyperactivity Disorder (ADHD; Vaurio et al., 2009).

Questionnaires

Barratt Impulsiveness Scale version 11 (BIS-11). The BIS-11 (Patton et al., 1995) is composed of 30 items, measuring different aspects of impulsivity via self-report on a 4-point Likert Scale (Rarely/Never, Occasionally, Often, Almost Always/Always); high scores imply more pronounced traits. The mean BIS-11 total score in the present sample equalled 64.33 (*SD* = 9.13). In addition to a total impulsiveness score, three higher-order factors: Attentional Impulsiveness (e.g. “I concentrate easily”), Motor Impulsiveness (e.g. “I act on the spur of the moment”) and Non-planning Impulsiveness (e.g. ”I am a careful thinker”) as well as six subscales: Attention, Motor Impulsiveness, Self-Control, Cognitive Complexity, Perseverance and Cognitive Instability disentangle the different aspects of impulsivity. Reliability coefficients were in the acceptable range in the current sample for the BIS-11 total score (ω_T = .9), the three higher-order factors (ω_T = .87, .72, .75 for the three factors, respectively) and the six subscales (ω_T = .81, .71, .74, .7, .65, .72, respectively). According to previous research, a BIS-11 total score above 72 is characteristic for highly impulsive participants (Stanford et al., 2009) and below 52 for over-controlled participants (Knyazev & Slobodskaya, 2006); the former is applicable to 19.8 % and the latter to 9.3% of the participants in the current sample.

Psychopathic Personality Inventory-Revised (PPI-R). The PPI-R (Lilienfeld & Andrews, 1996; Lilienfeld & Widows, 2005) consists of 154 items and was designed to measure psychopathic tendencies in non-criminal samples via self-report using a 4-point Likert scale, ranging from false to true. In the current student sample, a mean of 277.81 with a standard deviation of 34.34 was found, being similar to previously reported values found in the American validation sample (18 to 39 years: *M* = 283.6, *SD* = 32.27) and the Dutch forensic sample used for validation (*M* = 267.4, *SD* = 34.8; Lilienfeld & Widows, 2005). The PPI-R defines subclinical psychopathy in terms of a dimensional approach and does not depend on cut-off scores, but offers the possibility to compare individual scores to norm scores obtained in an European sample (Uzieblo et al., 2010). In the current sample, 24 participants would be considered potentially clinically significant as defined by a percentile above 65 in relation to the normal population (Uzieblo et al., 2010). The percentiles of the total score varied between 1 and 99 with a mean of 44.23.

Reliability coefficients for the PPI-R total score (ω_T = .96), its two higher-order factors: Fearless Dominance (e.g. “When my life gets boring, I like to take chances”; ω_T = .93), Impulsive Antisociality (e.g. “If I really want to, I can persuade most people of almost anything”; ω_T = .95) and its eight subscales (Machiavellian Egocentricity ω_T = .88, Social Potency ω_T = .86, Coldheartedness ω_T = .9, Carefree Nonplanfulness ω_T = .87, Fearlessness ω_T = .91, Blame Externalization ω_T = .92, Impulsive Nonconformity ω_T = .84 and Stress Immunity ω_T = .9) are high in the current sample.

Results

In line with previous approaches to the PGNG (Langenecker et al., 2005; Langenecker et al., 2007b, Langenecker et al., 2007a; Plewnia et al., 2013), separate one-way repeated-measures ANOVAs with PGNG Level as the within-subject variable (Level: 1, 2 or 3) were conducted on each of the dependent variables with a Greenhouse-Geisser correction applied where violations of sphericity were found. The data was found to be normally distributed and statistical analyses were carried out using IBM SPSS (Version 20). All reported p-values are corrected for multiple comparisons using the Bonferroni approach (multiplying the statistically determined p-value for each test by the number of comparisons made), and as such a corrected alpha level of .05 was used to assess significance. Reliability estimates for the questionnaires ($\omega_{T;}$ McDonald, 1999) as well as effect sizes and corresponding 95 % confidence intervals (CIs) for the statistical analyses were carried out using the program R (R Core Team, 2014) and the bias-corrected and accelerated bootstrap method (Efron & Tibshirani, 1993) was used to calculate the effect sizes and confidence intervals.

Participants were excluded if they displayed excessively poor performance on No-go trials (commission errors) in levels two and three (with poor performance defined as participants having a mean score of greater than 3 standard deviations away from the group mean), as this was taken to indicate a failure to understand the alternation rule. Failure to meet the stated criteria led to the exclusion of a total of six participants from the current research report.

Go Reaction Time

A significant main effect of Level was found for correct Go trials, $F(2,170) = 103.92$, $MSE = 1614.75$, $p < .0001$; $\eta^2_G = .21$, CI = .17 - .25. Post hoc comparisons with paired-samples t-tests indicated significantly slower responses at level 3 ($M = 569.98$, $SD = 81.55$), when difficulty was highest, compared to both level 1 ($t(85) = 13.51$, $p < .0001$, $d_z = 1.46$, CI = 1.25 – 1.67) and level 2 ($t(85) = 12.66$, $p < .0001$, $d_z = 1.46$, CI = 1.11 – 1.6). There was no difference between the reaction times obtained in the levels 1 ($M = 488.05$, $SD = 54.25$) and 2 ($M = 500.38$, $SD = 75.19$), $t(85) = 1.82$, p = NS.

Go/No-go Accuracy

A repeated measures ANOVA was performed on the percentage of correct responses to Go trials and showed no effect of Level ($M_{L1} = 97.54$, $SD = 3.55$; $M_{L2} = 97.21$, $SD = 3.91$; $M_{L3} = 96.78$, $SD = 3.93$) on PCTT ($F(2,170) = 1.43$, $MSE = 8.75$, p

= NS). Contrary to this, behavioural inhibition (PCIT) was affected by task difficulty (F(1,85) = 81.83, MSE = 134.87, p < .0001, η^2_G = .23, CI = .16 - .28), indicating better inhibitory control at level 2 (M = 83.59, SD = 11.74) compared to level 3 (M = 67.57, SD = 17.19). This finding is consistent with previous results using the PGNG and reflects the increasing task difficulty at level 3 compared to level 2.

Efficiency/Coefficient of variation

In agreement with the initial validation report on PGNG performance (Votruba & Langenecker, 2013), the efficiency ratio of the PGNG, balancing reaction time on Go trials with accuracy, was analysed and a significant difference across levels was found (F(1.76,145.84) = 161.33, MSE = 3.01, p < .0001; η^2_G = .32, CI = .27 - .36). Post-hoc comparisons indicated that the lowest efficiency score was associated with highest task difficulty, level 3 (M = 16.01, SD = 2.42), compared to the prepotent response acquisition stage, level 1 (t(85) = 19.89, p < .0001, d_z = 2.14, CI = 1.63 - 2.49) and to the low task difficulty level, level 2 (t(85) = 14.07, p < .0001, d_z = 1.52, CI = 1.2 - 1.81). Efficiency was also lower in level 2 (M = 19.17, SD = 3.04) than level 1 (M = 20.24, SD = 2.48), t(85) = 3.67, p < .005, d_z = .40, CI = .19 - .59.

When analysing the coefficient of variation, difficulty level influenced the dispersion of reaction times significantly (F(2,170) = 12.19, MSE = 9.39, p < .0001; η^2_G = .06, CI = .02 -.08). Paired-sample t-tests pointed towards greater dispersion at the highest task difficulty, level 3 (M = 19.01, SD = 3.42), compared to level 1 (t(85) = 5.21, p < .0001, d_z = .56, CI = .35 - .78) and level 2 (t(85) = 3.21, p < .05, d_z = .35, CI = .13 - .58). No significant difference was found between level 1, the prepotent response stage (M = 16.72, SD = 3.85) and level 2 (M = 17.6, SD = 4.23), t(85) = 1.69, p = NS.

Impulsivity, Psychopathy and the PGNG

To assess the relationship between inhibitory functioning as measured by the PGNG variable PCIT and the BIS-11 as well as the PPI-R, individual questionnaire scores for the BIS-11 and PPI-R were entered as covariates in separate repeated-measures ANCOVAs with Level as within-subject factor and PCIT as the dependent variable. Significant covariate effects of questionnaire scores on PCIT were followed by linear regressions to investigate individual differences in the relationship between inhibitory ability and impulsivity (BIS-11) and psychopathy (PPI-R) measures. Scatter plots of subscales showing significant relations to response inhibition-related variables of the PGNG are depicted in Figure 1. Furthermore, bivariate Pearson Correlation Coefficients were computed between the BIS-11 and PPI-R subscales, shown in Table 1.

No-go Accuracy and Impulsivity.

The BIS-11 subscale Cognitive Complexity expressed a significant main effect on PCIT (F(1,84) = 14.29, MSE = 258.17, p < .001; η^2_G = .1, CI = .02 - .17), while not interacting with difficulty level (F(1,84) = .71, MSE = 135.33, p = NS). To specify the type of influence Cognitive Complexity has on PCIT across levels, linear regression was performed, predicting mean PCIT across levels two and three from Cognitive Complexity. Linear regression showed that high scores on Cognitive Complexity significantly predicted reduced inhibition accuracy across levels (R^2 = .15, b = -1.99), indicating a higher level of experienced difficulty when performing response inhibition for participants scoring high on this impulsivity subscale.

In addition to the above approach, we also chose to perform an additional statistical analysis using a Bayesian framework. Within the Bayes framework it is possible to quantify the degree of evidence provided by the data for one hypothesis over another, including evidence for there being no difference, i.e. evidence for the null hypothesis (Kass & Raftery, 1995). For the experiment presented here our aim was to quantify the strength of the data in support of either (i) the hypothesis that there is a relationship between our personality factors (Cognitive Complexity & Blame Externalization) and inhibitory performance (PCIT), or (ii) for the null, that there are no personality related effects on inhibitory performance. This evidential value is presented as a Bayes Factor (BF) and is the ratio of the likelihood that the data support the experimental hypothesis over the null, with a ratio value of 3 taken as meaningful support for the hypothesis (Kass & Raftery, 1995). A Bayesian linear regression of PCIT with Cognitive Complexity yielded a BF of 86.72. We therefore have strong evidence in support of the hypothesis that Cognitive Complexity and PCIT are related.

The remaining subscales of the BIS-11 showed no significant relationship to response inhibition in the PGNG.

No-go Accuracy and Psychopathy.

The repeated measures ANCOVA indicated a specific negative relationship between one PPI-R subscale and response inhibition. The PPI-R Blame Externalization subscale showed a significant main effect on PCIT ($F(1,84) = 9.84$, $MSE = 270.41$, $p < .05$, $\eta^2_G = .07$, CI = .01 - .19) while not expressing a significant interaction with difficulty level ($F(1,84) = 1.81$, $MSE = 133.59$, p = NS). To specify how PPI-R Blame Externalization relates to response inhibition, linear regression was performed on the mean PCIT scores across the levels 2 and 3. The results indicated that high Blame Externalization scores predict reduced accuracy to inhibit pre-potent responding on No-go trials (R^2 = .11, b = -.49).

Using the same approach as outlined for assessing the evidence for our hypothesis that PCIT was related to Cognitive Complexity, we also applied a Bayesian linear regression to obtain a measure of support for the above finding of a significant relationship between Blame Externalization and PCIT. The resultant Bayes Factor was found to be 14.54, and represents strong evidence for the relationship between PCIT and Blame Externalization.

All other subscale and total scores of the PPI-R were not significantly related to No-go accuracy of the PGNG when correcting for multiple comparisons [3].

Discussion

The present research investigated the link between inhibitory functioning, impulsive behaviour and psychopathic personality traits in non-criminal participants. Specifically we used a recent version of the standard Go/No-go inhibition task, the parametric Go/No-go task that has similar inhibitory requirement as the standard Go/No-go but increases task demand on two additional associated executive functions, set shifting and mental updating. The main hypothesis was that the inclusion of a further executive function load to the basic requirement to inhibit would lead to a reduced capacity to inhibit prepotent responding, and that inhibitory performance would correlate with psychometric measures of impulsivity and psychopathic personality traits. The results of the PGNG showed that, in line with previous reports (Langenecker et al., 2005; Langenecker et al., 2007a; Votruba & Langenecker, 2013), as executive load increased from level 1 to level 3 of the PGNG task, reaction times and their dispersion increased while participants' ability to inhibit a prepotent response decreased, as did their response efficiency ratio. No effect of cognitive load was found on Go accuracies, contrary to earlier reports (Langenecker et al., 2007a). However, the absence of an effect here may be due to the inclusion of an inter-stimulus interval in the current design of the PGNG that did not feature in the earlier studies. The variable inter-stimulus intervals used here resulted in an inter-stimulus interval of, on average, 750ms, compared to no inter-stimulus interval in the original Langenecker et al. (2007a) report. We would suggest that this may account for the enhanced performance on Go trials since participants had more time to complete stimulus processing as well as to internally update the requirements for the next target stimulus prior to the appearance of the following stimulus in comparison to where stimuli are presented contiguously.

Associations between PGNG response inhibition and measures of impulsivity and psychopathic personality traits revealed several interesting findings. The measure of inhibitory ability, PCIT, was inversely predicted by Cognitive Complexity of the BIS-11. Participants who score highly on the Cognitive Complexity subscale of the BIS-11 are characterised by problems to focus on ongoing tasks and by being too impulsive to pursue mentally challenging activities (Patton et al., 1995). It is perhaps not surprising then that as the score on this subscale increases, individuals find the non-alternation rule of the PGNG more challenging. This finding, of increasing EF demands affecting inhibitory functioning in the PGNG for individuals who experience difficulty on challenging tasks, resembles previous findings for a complex Go/No-go task (Reynolds et al., 2006), which was conceptually similar to the PGNG, due to the incorporation of an increased working memory component while performing the inhibitory task. Reynolds et al. (2006) employed a task that required the participants to memorize four target numbers that indicated a Go response, while a further four numbers were classified as No-go stimuli. Interestingly Reynolds found a larger effect size than that found in the current study, r = .39 vs. .15, despite the fixed nature of the targets [4]. Both the study presented here, and the study of Reynolds and colleagues (2006), observed a relationship between the BIS-11 subscale of Cognitive Complexity and performance on inhibitory performance, which is in contrast to the results obtained using the standard Go/No-go task employed by Keilp et al. (2005) that related impulsivity to the higher-order factors of Attentional and Motor Impulsiveness of the BIS-11. While information on the individual subscales was not reported (Keilp et al., 2005), Cognitive Complexity forms part of the BIS higher-order factor of Non-planning, which did not show a relationship with performance on their Go/No-go inhibition task (Keilp et al., 2005). Taken together these findings suggest that it is the complexity of the Go/No-go tasks used here (alternating rule) and by Reynolds et al. (multiple targets) which is the key manipulation that leads to reduced performance related to high levels of the BIS first order factor of Cognitive Complexity. What remains to be determined is an operational definition of 'complexity'. Despite both the study here and Reynolds et al. utilising a more complex task, the nature of that complexity is not identical. In Reynolds et al. the complexity is in the form of a higher WM requirement, with 4 items to be responded to, and 4 to inhibit. Here the WM load effect (i.e. going from PGNG level 2 to level 3) did not show any interaction with Cognitive Complexity, but was maximally a WM load of only two items; rather the complexity was derived from the shifting nature of the No-go targets. Further work will be required to determine whether the alternating rule of the PGNG and the increased number of targets are tapping the same underlying deficit, as represented by high scores on Cognitive

Complexity. A notable absence was any effect of Motor Impulsiveness and Attentional Impulsivity that Keilp et al. (2005) identified with their standard Go/No-go task. We would suggest that the impact the increase in complexity has on performance is such that the influence of more basic aspects of impulsivity such as, for example, acting without thinking (Motor Impulsiveness) and quick decision making (Attentional impulsivity; Patton et al., 1995), are overshadowed on these complex forms of inhibition task, whereas the relative ease of the standard Go/No-go task leaves more room for these aspects of impulsivity to be observed.

In addition to the Cognitive Complexity subscale of the BIS-11, the psychopathy component, Blame Externalization also predicted a drop in performance when participants were required to inhibit their responses as governed by the alternation rule, which corresponds to an increased load on executive functions when compared to the standard Go/No-go task. Similar to the current finding Sadeh & Verona (2008) reported a negative correlation between the PPI-R subscale Blame Externalization and working memory performance under high cognitive load in a working memory task. Additionally, previous research has reported a positive association between the concept of disinhibition and the Blame Externalization subscale, highlighting its importance for inhibitory ability (Drislane, Patrick, & Arsal, 2014) and mirroring its conceptualization as part of the PPI-R factor Impulsive Antisociality (Lilienfeld & Widows, 2005). Further evidence for the importance of the Blame Externalization subscale stems from research into criminal correlates, which found the PPI-R Blame Externalization subscale to be predictive of career delinquency and aggression in correctional samples, the latter being related to reduced inhibitory ability (DeLisi et al., 2014; Kimonis et al., 2006; Sandoval, Hancock, Poythress, Edens, & Lilienfeld, 2000; Vigilet-Colet & Codorniu-Raga, 2004). Given the similarity of the findings for BIS-11 Cognitive Complexity and PPI-R Blame Externalization, correlations among these measures were carried out and the lack of a significant association between those two subscales supports the view that, while both subscales express a similar relationship to inhibitory performance in the PGNG, they represent different aspects of personality.

As described earlier, the Blame Externalization subscale is part of the Impulsive Antisociality factor of the PPI-R, which in turn would be expected to be related to tasks measuring response inhibition, since response inhibition is one part of the multifaceted impulsivity construct (Keilp et al., 2005; Reynolds et al., 2006; Sharma et al., 2013; Spinella, 2004). However, the relationship between this PPI-R factor and reduced inhibitory performance did not survive corrections for multiple comparisons in the current study. Furthermore, the PPI-R Carefree Nonplanfulness subscale, which also loads on the PPI-R Impulsive Antisociality factor, was not related to response inhibition in the current task. Carefree Nonplanfulness refers to an inability to plan ahead, which is indicative of impulsivity as also captured by the BIS-11 Nonplanning Impulsiveness factor (Patton et al., 1995) and the current results suggest that both tap aspects of impulsivity outside of those measured by response inhibition. These results are further consistent with the previously reported absence of a relationship between PPI-R Carefree Nonplanfulness and cognitive load in a working memory task (Sadeh & Verona, 2008).

The absence of a significant relationship between response inhibition and the PPI-R factor Impulsive Antisociality warrants some discussion. Power calculations indicate that the current sample size enabled the detection of effect sizes in the medium range, precluding strong conclusions about current null results. As such, there might be uncovered relationships between inhibitory performance and impulsivity as well as psychopathy aspects, which were too small to be detected with the current study design and the conservative correction for multiple comparisons. Furthermore, a decline in motivation might have contributed to the interaction between psychopathic, as well as impulsivity aspects, and deficits in response inhibition. The current task design, counterbalancing levels 2 and 3 across participants, attempted to control for possible motivational decline as well as fatigue effects, which might have been higher in impulsive participants as well as in participants expressing a higher level of psychopathic traits. However, motivation was not measured directly, which should be addressed in future studies. Another limitation of the current study relates to the choice of the impulsivity questionnaire, the BIS-11. Recent research indicates some controversy about the factor structure of the BIS-11, such as non-replicable factor structures in community samples, and therefore there is a question of its utility in research areas relating to populations that display high impulsivity levels, such as addiction, gambling and hypersexuality, and community samples (Reid, Cyders, Moghaddam, & Fong, 2014; Reise, Moore, Sabb, Brown, & London, 2013). Future studies should consider replication of the current results with alternative self-reports of impulsivity, as for example the UPPS-P Impulsive Behavior Scale (Whiteside & Lynam, 2001), which shows acceptable associations to externalizing behaviours, such as aggression and antisocial behaviour (Carlson, Pritchard, & Dominelli, 2013; Lynam & Miller, 2004).

Despite these limitations, the current results point towards several important considerations. For example, the absence of a relationship between the overall psychopathy score and response inhibition is consistent with the notion that the psychopathic personality is composed of different aspects, that might not uniformly relate to deficits in response inhibition or impulsivity in general (Feilhauer, Cima, Korebrits, & Kunert, 2012; Snowden & Gray, 2011), and explains previous null findings on the behavioural level when relying solely on total scores of psychopathy instruments (Carlson & Thai, 2010; Kim & Jung, 2014).

A key motivation for this study was to try and understand why, in the face of observable difficulties in maintaining goals and inhibiting socially inappropriate behaviour, psychopathic participants consistently fail to show a consistent pattern of performance on measures of response inhibition. Based on our observation that most inhibition tasks do not take into account the unity and diversity of EF (Miyake et al., 2000; Friedman et al., 2008), we reasoned that an inhibitory task that parametrically taxed several EF simultaneously would reveal load based changes in inhibitory performance, which was the case when seen independently of impulsivity and personality variables. However, we did not identify any PGNG load based effects on inhibitory performance when relating inhibitory ability to impulsivity and subclinical psychopathy, and as such the data do not support a shifting resource hypothesis underlying impulsivity and subclinical psychopathy. However, as discussed above, the finding of a strong relationship between inhibition and aspects of impulsivity and psychopathy when incorporating set-shifting and WM updating into an inhibitory task clearly highlights the importance of examining inhibitory performance in the context of other executive functions and in individual differences in performance, such as in subclinical psychopaths. Similarly to subclinical psychopathy, whose deficits in response inhibition are related to the load on the shared executive functions, a recent meta-regression analysis on ADHD found inhibitory deficits to be most pronounced as cognitive load requirements are increased (Huizenga, van Bers, Plat, van den Wildenberg, & van der Molen, 2009). In addition to subclinical psychopathy and ADHD, the manipulation of cognitive load has been highlighted as being important when investigating inhibitory deficits in bipolar disorder (Langenecker et al., 2010; Ryan et al., 2012). Here, similarly to subclinical psychopathy, static response inhibition as conceptualized in the standard Go/No-go task does not capture the response inhibition deficit, whereas the PGNG as a contextual response inhibition task consistently reveals the state and trait deficits in inhibitory ability (Langenecker et al., 2010; Ryan et al., 2012).

The data presented here would suggest that previous research that did not find a strong link between psychopathic traits and measures of inhibitory ability (Carlson & Thai, 2010; Kim & Jung, 2014) could have been the result of the relative simplicity of the inhibitory task. Here, the key experimental factor that impacts inhibitory performance is the requirement to flexibly adapt response behaviour in the light of changing context, therefore testing inhibitory functioning while executive functions are being utilised to a greater degree than is the case with the standard version of the Go/No-go task (Langenecker et al., 2007a). This is the first application of the PGNG paradigm to subclinical psychopathy and impulsivity and further investigation is required to ascertain the mechanism via which individual differences manifest. Additionally, future research should aim to replicate the current association between aspects of psychopathy and response inhibition deficits as measured by the PGNG in forensic samples to ascertain the here proposed link between psychopathy and inhibitory deficits.

In summary, the current investigation adds to the validity of the PGNG by establishing specific relationships between the PGNG variables and measures of impulsivity and psychopathy, reflecting task demands. The results suggest that the PGNG is sufficiently sensitive to individual differences in response inhibition and has considerable utility as a measure of impulsivity by taking into account the underlying association of executive functions, forming a shared capacity that is taxed by this task.

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Footnotes

[1] Although not directly relevant to the argument here, it should be noted that in addition to the on-going debate about what should be considered an EF, there have been arguments concerning whether the suite of EFs constitute a unitary construct or a number of diverse functions (e.g. Baddeley, 1996; Duncan, Johnson, Swales & Freer, 2001; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001).

[2] The data presented here were collected in two rounds. The first round of data collection involved 60 participants. Based on an interim analysis of the first 60 participants, data from a further 26 participants was deemed necessary to achieve the required power. To alleviate any concern regarding a potential inflation of the statistical outcome, theoretically critical findings were also analysed using a Bayesian approach where additional data collect/analyse cycles do not carry the same potential for error inflation as frequentist statistics.

[3] The PPI-R factor Impulsive Antisociality expressed the same relationship to response inhibition as blame externalization ($F(1,84) = 6.03$, $MSE = 281.85$, $p_{uncorr} = .02$, $\eta^2_G = .05$, CI = .004 - .11; $R^2 = .07$, $b = -.15$), but this finding did not survive correction for multiple comparisons. The analyses on Blame Externalization as well as Cognitive Complexity were additionally carried out with repeated measures ANCOVAs adding gender as a covariate. The results showed no influence of gender (all *F*s > .6) and the inclusion of gender as a covariate did not alter the significance of the remaining results on Blame Externalization and Cognitive Complexity.

[4] To note, the effect sizes reported here are of the same magnitude as found in Keilp et al. (2005), where the standard version of the Go/No-go was employed ($r = .37 - .38$). The effect size obtained here is comparable to previous research on the relationship between BIS-11 impulsivity and other versions of the Go/No-go task.

However, Keilp at al. (2005), examined the relationship between the Attentional and Motor Impulsiveness factor scores and Go/No-go performance and as such it is unclear which individual BIS-11 subscales were related to performance in the standard Go/No-go task, whereas in the PGNG a specific relationship between response inhibition accuracy and impulsivity relating to Cognitive Complexity existed.