The Inhibitory Spillover Effect:
How increased urination urgency enhances accuracy on reaction time tasks

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ABSTRACT

Evidence from neuropsychological research has implicated specific regions in the brain as the control centres for all types of inhibitory processes. One aspect of this inhibitory network system that has been explored is the spillover of inhibition from one domain to another. The idea that inhibition in one area can lead to inhibition in another area has been termed the *Inhibitory Spillover Effect* (ISE). This effect has been examined in applied settings such as lie detection where it is alleged that inhibition in one domain (suppression of the desire to urinate) has led to superior deception allegedly due to an increased ability to suppress deceitful cues. Further research investigating this effect in decision-making has also revealed enhanced restraint over impulses; however, no research has examined whether the ISE really does have an effect on cognitive tasks that are expressly designed to examine the processes of inhibition. Therefore we examined the effect of inhibiting urination on performance of two Go/No-go tasks and two CRT tasks that have been proven to activate inhibitory processes. From a sample of 30 University undergraduates, we compared reaction time and accuracy performance of individuals inhibited in the motor domain (increased urge to urinate) with individuals who were not. Our findings revealed a spillover effect onto these cognitive processes, with inhibited individuals less prone to error than the control group. As reaction time remained the same for both groups we suggest that the ISE reduces speed-accuracy trade-offs, with inhibited individuals processing correct responses without a detrimental effect to speed. The findings from this study offer new insight into the results found in applied research, indicating the ISE as highly beneficial to everyday functioning. Future research may explore the post-effects of urination inhibition on the same processes in order to determine whether performance is impaired.

KEY WORDS:	THE INHIBITORY SPILLOVER EFFECT	ACCURACY PERFORMANCE	REACTION TIME	COGNITIVE PROCESSING	URINATION URGENCY

Introduction

Being able to inhibit inappropriate actions, thoughts and feelings is an important tool when it comes to functioning in the real world. The ability to inhibit certain responses not only benefits us socially, but it also allows us time to produce intelligent cognitive analyses within a changing environment (Sternberg & Kaufman, 2002). According to Gray's theory of the Behavioural Inhibition System (BIS; 1972), we may define inhibition as a vigilance mechanism that enables us to avoid behaviours that may have a negative outcome. The influence of inhibition has been found to extend to cognitive, affective and motor processes, enabling us to ignore painful emotions for example, or control bladder urgency. Even though the subjective experiences of these forms of inhibition feel different from one another they may all share a similar neurocognitive system. Within the last decade, neuropsychological research has introduced the idea of a spillover effect of inhibition within this system, as a result, recent research has focused on how the spillover can have an effect in various applied settings such as lie detection and decision making (Fenn et al, 2015; Tuk et al, 2011). Considering this however, there has been little research exploring the fundamental mechanisms that are claimed to underpin the results found in applied settings. The purpose of the current study is to explore the primary mechanisms underlying the spillover effect using cognitive tests that have been proven to reveal basic aspects of inhibition.

As discussed above, it is alleged that there is a single neurocognitive system underpinning all inhibition including forms of affective, cognitive and motor inhibition. The evidence comes from various neuropsychological studies implicating regions including the right inferior frontal cortex (rIFC), anterior cingulated cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) as having a role in response inhibition of separate motor (Aron et al, 2003; Picton et al, 2007; Simmons, Pekar & Mostofsky, 2008), cognitive (Jonides et al, 1998; Menon et al, 2001), and affective domains (Kim & Hamann, 2007; Ochsner et al, 2004). Damage to this region is further support for its involvement in inhibition with ability to inhibit motor responses impaired when the rIFC is deactivated (Chambers et al, 2006). Until recently, these forms of inhibition were studied independent of one another, with no investigation into their influence on each other. Berkman and colleagues (2009) set out to explore just this and established an inhibitory neural network system within the rIFC. By intentionally inhibiting individuals in the motor domain using a Go/No-go task, they demonstrated a simultaneous spillover of inhibition into the affective domain, where inhibited individuals showed reduced amygdala activity when faced with negatively-valenced stimuli. Thus, when inhibited in one domain either deliberately or unintentionally, one is subsequently inhibited in another domain; this is called the *Inhibitory Spillover Effect* (ISE).

In reaction to this novel finding, subsequent research has examined the role of the ISE on inhibitory tasks and decision-making, revealing that the ISE enhances performance. Inducing physiological inhibition (full bladder) has been found to improve speed on tasks that rely on inhibition such as the stroop test (Tuk et al, 2011). Furthermore, a full bladder has been shown to increase the ability to resist impulsive choices in monetary decision-making (Tuk et al, 2011). The enhanced ability to inhibit behaviour within decision-making, which Tuk and colleagues refer to as 'intertemporal patience' (p.9) was reproduced when individuals were just visually primed to the ISE. Participants exposed to a water-related word search reported higher levels of urgency than the control group, as a result they showed a greater preference for delayed but enhanced monetary rewards. With the same inhibitory benefits of actual bladder fullness produced by priming, the influence of the ISE is not just limited to physiological triggers. Reduced impulsivity was also shown when inhibition was induced in the cognitive domain through a thought suppression task. Tuk and colleagues (2012) found that individuals inhibiting thoughts of a white bear showed greater intertemporal patience than those who were not restrained in their thinking. The ISE not only enhances ability to make better financial decisions but has also been found to increase self-control over food consumption (Tuk et al, 2012). In line with the 'ego depletion effect' (Baumeister, 2002) however, the ISE occurs only when inhibition tasks are presented simultaneously. Once the inhibitory processes are no longer in use, self-control depletes, as does performance on subsequent inhibitory tasks. This is evidenced in a continuation of Tuk's research (2012), where previously inhibited participants consumed more crisps in the sequential task than the control group. Considering this, the enhanced performance shown on tasks due to the ISE may be at the expense of performance on tasks committed post-experiment. Along with timing, individual differences in BIS sensitivity (Gray, 1972) have also been found to moderate the influence of the ISE. Considering that the BIS been associated with the ACC (Amodio et al, 2008), an area involved in the ISE (Berkman et al, 2009), research has revealed that individuals with greater BIS activity are more susceptible to inhibitory spillover effects (Tuk et al, 2011, 2012). With personality traits along with physiological and environmental factors triggering spill over effects, various other behaviours are likely to be influenced. Where the ISE has been found to enhance performance in decision-making, similar results have been observed in applied areas of deception.

Recent research investigating the role of bladder urgency on lying ability has revealed further benefits of being under the influence of the ISE (Fenn et al, 2015). Working on the basis that deceiving requires an increased access to inhibitory processes (Gombos, 2006), inhibited individuals induced using the urination urgency method proved more convincing when lying than those uninhibited. The ability to avoid detection was measured on performance on three separate cues, cognitive load, anxiety (indicators of deceit), and confidence & convincing appearance (indicators of truth). The effect of inhibition spilled over into the behavioural domain enabling liars to inhibit signs of deceit and show more signs of truth telling than truth-tellers themselves as well as uninhibited liars. While these findings provide a highly interesting perspective on the role of inhibition in controlling certain behaviours, it introduces ethical concerns for real life detection environments, with only liars benefitting from such information. Regarding our receptiveness to spillover effects triggered by various cues as well as the influence it has on behaviours, it seems important to investigate its role on the most basic processes involved in everyday functioning.

In general, research into the ISE presents the role of inhibition as advantageous to behaviour, reporting conclusions of enhanced control in decision-making and deception. The settings in which these results apply although very exciting, fail to examine the ISE at its most basic level. While we know which regions in the brain are activated by the ISE (Berkman et al, 2009), there is a lack of research directly testing its effect on fundamental cognitive processing tasks. Although stroop tasks have been used to test the role of ISE (Tuk et al, 2011), the processes they measure are still fairly complex compared to basic choice reaction time (CRT) tests (Takahashi, Turek & Moore, 2001). Considering that Berkman (2009) used a Go/No-go task to *induce* inhibition, this study uses the same test along with a regular CRT to measure the *effect* *of* inhibition. As these reaction time tasks both involve the process of discrimination (Snodgrass, Berger & Haydon, 1985) we should have little problem in revealing the influence of the ISE on basic inhibitory processes. In order to determine what effect it has on these processes, inhibition will be induced in the motor domain by manipulating urination urgency and performance will be measured against an uninhibited control group. Failing to find any significant findings at this most basic level of processing would suggest that the results from the previous studies are not caused by the ISE. Considering the numerous approaches to inducing inhibition, this study utilizes the urination pressure method as used in previous studies because of its association with the ACC (Griffiths & Tadic, 2008). Investigating this effect on reaction time tasks will allow us to see how both cognitive and motor processes are influenced and thus infer its role in everyday behaviours.

Reaction time tasks have long been used as a method of measuring the speed of mental operations (Posner, 1978). In such tasks, these operations are outputted as a motor response (Bernal & Altman, 2009) like that of pressing a button. The information gained by examining the influence of external factors on these processes enables us to better understand real life phenomena. Numerous experiments have revealed specific factors including stress (Panayiotou & Vrana, 2004), gender (Noble et al, 1964), age (Jevas & Yan, 2001), and practice (Sanders, 1998) as all influential to reaction time. While inhibition has been physiologically implicated in the performance on CRT tasks (Burle et al, 2004), no research has directly tested the effect of induced inhibition on such tasks. Performance on regular CRT tasks involves making a response that corresponds to the stimulus presented; left arrow; left arrow, right arrow; right arrow. As CRT tasks involve both preparatory and anticipatory responses, the individual constantly needs to inhibit responses to competing incorrect alternative cues (Kornblum, 1965). Because inducing inhibition within an individual enables greater access to this tool, performance on such a task should be aided and thus enhanced for those deliberately inhibited. Evidence supporting the role of the inhibitory network system in enhancing performance on CRT tasks is implied by rat studies, with lesions to the ACC impairing discriminative accuracy on a 5-choice serial reaction time task (Chudasama et al, 2003). As the ACC is associated with the ISE, it is no surprise that damage to this area impairs performance on inhibitory related tasks. Interestingly increased ACC activity has also been found to enhance reaction times in a simple reaction time task (Naito et al, 2000), however further research implies accuracy as a result, declines (Mulert et al, 2003). This finding can be attributed to the speed-accuracy trade-off hypothesis (Fitts, 1954) where only one can be enhanced at the expense of the other. In view of this, the present experiment intends to examine both accuracy and reaction time as a means of measuring performance. On the basis that inhibition allows individuals to calculate the most appropriate response before they act (Sternberg & Kaufman, 2002) as shown in decision-making (Tuk et al, 2011), inhibited individuals in the current study may show greater accuracy at the expense of response times. As a result, we may see faster reaction times within the control group compared to those inhibited.

As well as CRT tasks, this study will also test performance on Go/No-go reaction time tasks. Performance on such tasks typically involves responding to one set of stimuli (Go) and inhibiting responses to a different set of stimuli (No-go). Like the CRT, inhibition has been empirically evidenced as an aspect of the Go/No-go task (Berkman et al, 2009). Although the task has been used as a method of inducing inhibition for the ISE, the influence of the ISE itself on this task has not been examined. Considering that performance on this type of task is primarily concerned with inhibiting responses, the ISE like in the CRT task should increase accuracy for those already inhibited. Evidence for the role of inhibition in enhancing accuracy in this type of task comes from research of chronic cocaine users in stop-signal tasks. As cocaine abuse is known to cause severe deficits in inhibitory functioning (Lyvers, 2000), users showed a reduced ability in inhibiting responses to No-go stimuli (Fillimore & Rush, 2002). Considering that the present study examines individuals manipulated to have access to enhanced inhibitory functioning, the effects we see should be reversed, with them showing greater ability in inhibiting No-go responses.

In addition to these tasks, we will manipulate the number of choices for both tests in order to demonstrate a greater distinction between the two groups. The idea is that, as the number of alternative responses increase, so does the demand on these inhibitory processes (Kornblum, 1965). Considering this, the present study will test performance on both a Two-itemed and Ten-itemed Go/No-go and CRT task, where those deliberately inhibited will show better performance when more inhibition is required (Ten CRT, Ten Go/No-go) than those in the control group. According to Hicks Law (1952), regardless of the ISE, all participants should show a significant increase in reaction times when completing the Ten itemed tasks compared to the Two itemed tasks as more time is required in order to process the excess information.

The current study investigates the basic cognitive processes that are thought to play a role in the ISE. In relation to previous conclusions on behaviour, we expect to see greater accuracy in inhibiting incorrect responses on these tasks for those already inhibited, where a greater difference inhibitory groups is shown when more choices are available. As a result of increased accuracy, those inhibited may be slower in their reaction times than those in the control group according to the speed-accuracy trade off effect. Revealing such findings at this most basic level will contribute to the understanding of the ISE and will provide evidence about whether or not effects of a full bladder in applied settings can be attributed to the ISE.

Method

Participants

A sample of 30 Portsmouth University undergraduates were used in this experiment. Ages ranged from 18-23 (*M*=19.00, *SD*=1.20), with 19 females and 11 males distributed between groups. Participants were recruited either through the Portsmouth University's participant pool system in return for course credits or responded to a poster advertisement displayed within King Henry building. Only one participant's data was withdrawn as they left before completing the reaction time tasks due to excessive urination urgency.

Design

A simple one-factor two levels between-subjects design was used to assess urination urgency (low urgency for urination vs. high urgency for urination) on accuracy and latency of four choice reaction time tasks (Two CRT, Ten CRT, Two Go/No-go & Ten

Go/No-go). Participants were randomly assigned to either the low urgency group, which involved drinking 50ml of water or the high urgency group, which involved drinking 700ml[a].

Materials

Demographic information including, age, gender, occupation and subject of study were recorded. For both conditions 700ml of bottled water was distributed between five plastic cups labelled A-E (although of course there was no difference in the taste of the water in each of the cups). A five-itemed questionnaire concerning the taste and aesthetics of the water was used (again this was just to maintain the fiction of the study). For the filler task, 45 minutes of a nature documentary was shown with a follow up questionnaire consisting of 10 questions concerning the content of the documentary. Two questions were used to assess participants' level of urination urgency and stress level. For urination urgency, responses to the question, "How urgently do you feel the need to urinate?" were scored on a 7-point scale (from 1, *not urgently at all*, to 7, *very urgently*). For stress levels, responses to the question, "How stressed do you feel?" were also scored on a 7-point scale (from 1, *not stressed at all*, to 7, *very stressed*).

Computer tasks

CRT tasks

Both tasks were presented on a computer screen. For the Two CRT task, the numbers 1 and 2 were presented, while in the Ten CRT task, numbers ranging from 0-9 were presented. All numbers were presented sequentially on the screen. Both tasks involved 20 trials with each of the numbers used presented the same amount of times as the rest. In the Two CRT task for example, the numbers 1 and 2 were both presented 10 times, while in the Ten CRT task, each number was presented two times. The presentation order of the numbers was random. Pressing any other number than that shown on the screen was recorded as incorrect. Delayed responses (five seconds or more) were also recorded as incorrect. For all incorrect responses, the word 'Incorrect' in red letters was immediately presented on the screen. Reaction times were recorded for all responses.

Go/No-go tasks

Both tasks were presented on a computer screen. For the Two Go/No-go task, the numbers 3 and 4 were presented while the Ten Go/No-go task used the same range as the Ten CRT task. All the numbers were presented sequentially on the screen. Each task involved 30 trials where the correct stimulus (Go) was presented 20 times while the alternative stimuli (No-go) were presented only 10 times. Within the Ten Go/No-go task, each of the alternative numbers were presented once except from the number 2 which appeared twice. The presentation order of the numbers was random.

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[a] As the average adult bladder usually contains 300 ml of urine and is reasonably full when it contains 500 ml (Marieb et al, 2007), those in the high inhibitory condition were likely to experience substantial motor inhibition.

Any response to the alternative stimuli as well as a missed response to the correct stimuli (five seconds or more) was recorded as incorrect. For these responses, the word 'Incorrect' was also immediately displayed on the screen. Reaction times were only recorded for the Go responses.

Procedure

The Inhibitory task

Before attending the experiment participants were instructed not to arrive with a full bladder, as there would be no opportunity during the hour-long experiment to leave for the toilet. On arrival, all individuals read and signed an informed consent. After giving consent, participants took a seat in front of the filled cups and were instructed to drink either the full amount of all the cups (high inhibitory group) or sip each of them (low inhibitory group). They were told to drink each of the cups in a consecutive order and inform the experimenter once finished. Individuals were not timed in their completion of this task. In order to avoid demand characteristics, all participants were led to believe that the water instruction was part of a taste test. In keeping with this deception, participants subsequently answered a five-itemed taste-test questionnaire concerning the water. Following this, both groups were asked to fill out some demographic questions as well as complete several filler tasks during a 45-minute interval[b]. Once the experiment had been completed, participants rated their level of urination urgency to confirm participant motor inhibition. As participants were misled, a debrief of the real aims of the study was given as well as a debrief consent form. Cups were checked post experiment within the high inhibitory condition to confirm the full volume had been drunk.

Computer tasks

Following the 45-minute interval, all participants were tested on latency and accuracy on both a Two-itemed and Ten-itemed choice reaction task, as well as a Two-itemed and Ten-itemed Go/No-go task. For the CRT tasks, participants had to press a number on the keypad corresponding to the number presented on the screen. For the Go/No-go tasks, participants had to press the spacebar when a specific number was presented on the screen. For the Two-Go/No-go, participants were instructed to press spacebar when the number 3 was presented and inhibit a response when the number 4 was shown. For the Ten-Go/No-go, participants were instructed to press spacebar only when the number 5 was shown and inhibit responses to all other numbers ranging from 0-9. All participants were instructed to respond as fast as they could whilst simultaneously avoiding making any mistakes.

Results

Was the motor inhibition manipulation successful?

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[b] Depending on the body size, the average time for liquid to reach the bladder is between 20 minutes to 3 hours (Marieb et al, 2007). Participants were still awarded credits when they could not complete the full length of the study.

A manipulation check revealed that individuals in the high inhibitory condition reported higher levels of urination urgency (*M*=3.80, *SD*=2.40) than those in the low inhibitory group, (*M*=2.13, *SD*=1.30), *t(*28)=-2.37, *p*=.025 (2-tailed), *d*=.87, with a large effect size. Therefore the manipulation was successful.

Can the results be attributable to changes in stress rather than inhibition?

There was no significant effect of condition on stress, with both high (*M*=1.93, *SD*=1.03) and low (*M*=1.87, *SD*= .74) inhibitory groups reporting similar stress levels, *t(*28)=.20 *p*=.841 (2-tailed), *d*=.07. The confidence interval of difference provides further confirmation of this non-significant effect as the confidence interval of the difference runs through zero (*CI* 95% [-.74, .61]). This indicates that any effects are due to urination urgency rather than stress.

The effect of inhibitory condition on accuracy performance

The initial analysis was an overall independent groups MANOVA used to assess the effect of condition (low inhibitory group vs. high inhibitory group) on the incorrect response data of the four tasks (Two CRT, Ten CRT, Two Go/No-go & Ten Go/No-go). A significant multivariate effect of inhibitory condition was found in incorrect responses with a large effect size, Wilks' λ=.68, $F(1,25)=2.97$, $p=.039$, $\eta_p^2 = .32$.

The significant MANOVA justified the use of four individual univariate ANOVAs, conducted to assess the effect of condition (low inhibitory group vs. high inhibitory group) on incorrect responses of each individual task (Table 1). There was no significant main effect of condition on the Ten CRT or Two Go/No-go tasks. However, accuracy performance in the Ten Go/No-go task was significantly higher in the high inhibitory group than in the low inhibitory group, with a small effect size. A similar pattern was observed for the Two CRT with the high inhibitory group making less incorrect responses than the low inhibitory group, however the result only approached significance.

Table 1.
Incorrect responses of four tasks as a function of inhibitory condition (n=30).

The effect of low choice and high choice tasks and condition on accuracy performance

Measure	Low (n=15)		High (n=15)		df	*F*	*P* (2-tailed)	η_p^2
	M	SD	M	SD				
Two CRT	1.27	1.75	.33	.62	1,28	3.79	.062	.12
Ten CRT	.93	1.10	.40	.63	1,28	2.65	.115	.09
Two Go/No-go	.13	.35	.27	.46	1,28	.80	.379	.03
Ten Go/No-go	.40	.63	.01	.01	1,28	6.00	.021	.18

The purpose of the following tests were to investigate whether or not the effect of inhibition is stronger in the high choice tasks (Ten-itemed) than in the low choice tasks (Two-itemed) in terms of incorrect responses. In order to investigate this question a series of 2 X 2 mixed ANOVA's were conducted (Table 2). The independent groups factor was condition (low inhibitory group vs. high inhibitory group) and the repeated measures was type of test (low choice vs. high choice).

Table 2.
Incorrect responses as a function of condition and type of test.

Source	Low			High			df	*F*	*P*	η_p^2
	N	M	SD	N	M	SD				
Condition CRT	15	1.10	1.42	15	.37	1.25	1,28	7.88	.01	.22
Task CRT	30	.80	1.37	30	.67	.92	1,28	.18	.677	.01
Condition x Task CRT	-	-	-	-	-	-	1,28	.40	.533	.01
Condition Go/No-go	15	.27	.49	15	.13	.23	1,28	1.18	.29	.04
Task Go/No-go	30	.20	.41	30	.20	.48	1,28	.01	1.01	.01
Condition x Task Go/No-go	-	-	-	-	-	-	1,28	7.59	.01	.21

Note. For source condition, *Low* refers to the Low Inhibitory group and *High* refers to High Inhibitory group. For source Task, *Low* refers to Two-itemed tasks, while *High* refers to Ten-itemed tasks.

Low and high choice CRT

With reference to Table 2, we can see that there was a significant difference in incorrect responses between the low and high inhibitory groups with a medium effect size. There was no significant difference however found in incorrect responses between the Two CRT and Ten CRT task. No condition x task interaction effect was found in incorrect responses. Therefore, the effect of inhibition was not stronger in one task than the other but overall, the high inhibitory group made less incorrect responses than the low inhibitory group confirming the earlier analysis.

Low and high choice Go/No-go

From Table 2 we can see that there was no significant difference found in accuracy performance between the low and high inhibitory groups. There was also no significant difference found in incorrect responses between the Two Go/No-go and Ten Go/No-go task. A significant condition x task interaction effect was found in incorrect responses with a medium effect size. It is clear from *Figure 1* that the interaction was found because there was no effect of inhibitory condition in the Two-choice task whereas in the Ten-choice accuracy performance was superior in the high inhibitory group. Simple main effects analysis confirmed this interpretation with no significant difference between groups in the Two-choice (*p*=.37, n.s) while there was within the Ten-choice (*p*=.021). Therefore, the effect of inhibition on accuracy performance was influenced by the task involved, with a stronger effect shown in the high choice task than in the low choice.

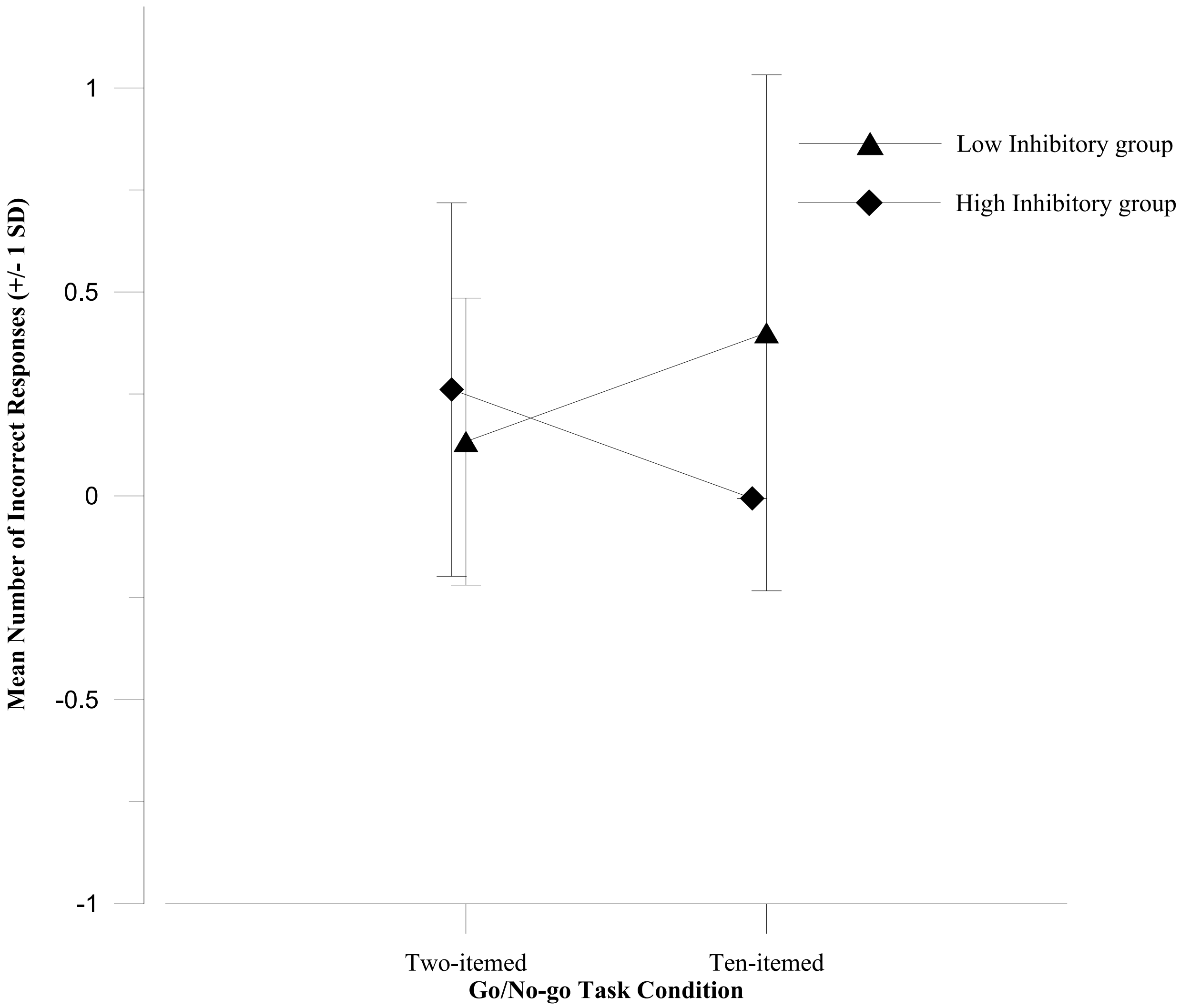

Figure 1. Number of Incorrect Responses on both a Two-itemed and Ten-itemed Go/No-Go Task as a Function of Inhibitory Condition (*N*=30).

The effect of inhibitory condition on reaction time performance

An overall independent groups MANOVA was used to assess the effect of condition (low inhibitory group vs. high inhibitory group) on the reaction times of four tasks (Two

CRT, Ten CRT, Two Go/No-go & Ten Go/No-go). No significant multivariate effect of inhibitory condition was found in reaction times, Wilks' λ=.95, $F(1,25)$=.34, p=.849, η_p^2 = .05.

Four individual univariate ANOVAs were conducted to assess the effect of condition (low inhibitory group vs. high inhibitory group) on reaction times of each individual task (Table 3). There were no significant main effects of inhibitory condition found in reaction times of each task.

Table 3.
Reaction times (seconds) of four tasks as a function of inhibitory condition (n=30).

The effect of low choice and high choice tasks and condition on reaction time performance

Measure	Low (n=15)		High (n=15)		df	*F*	*P* (2-tailed)	η_p^2
	M	SD	M	SD				
Two CRT	.46	.04	.45	.04	1,28	.35	.556	.01
Ten CRT	.85	.11	.88	.10	1,28	.52	.479	.02
Two Go/No-go	.49	.09	.50	.09	1,28	.01	.955	.01
Ten Go/No-go	.53	.14	.52	.16	1,28	.07	.796	.01

The purpose of the following test was to investigate whether or not the effect of inhibition is stronger in the high choice tasks (Ten-itemed) than the low choice tasks (Two-itemed) in terms of reaction time. In order to investigate this question a series of 2 X 2 mixed ANOVA's were conducted (Table 4). The independent groups factor was condition (low inhibitory group vs. high inhibitory group) and the repeated measures was type of test (low choice vs. high choice).

Table 4.
Reaction time (seconds) as a function of condition and type of test.

Source	Low			High			df	*F*	*P*	η_p^2
	N	M	SD	N	M	SD				
Condition CRT	15	.65	.07	15	.66	.07	1,28	.17	.688	.01
Task CRT	30	.45	.04	30	.87	.10	1,28	565.66	*p*<.001	.95
Condition x Task CRT	-	-	-	-	-	-	1,28	1.04	.318	.04
Condition Go/No-go	15	.51	.12	15	.51	.12	1,28	.02	.886	.01
Task Go/No-go	30	.50	.09	30	.52	.15	1,28	3.58	.069	.11
Condition x Task Go/No-go	-	-	-	-	-	-	1,28	.28	.60	.01

Note. For source condition, *Low* refers to the Low Inhibitory group and *High* refers to High Inhibitory group. For source Task, *Low* refers to Two-itemed tasks, while *High* refers to Ten-itemed tasks.

Low and high choice CRT

From the information presented in Table 4 we can see that there was no significant difference found in reaction times between the low and high inhibitory groups. There was however, a significant difference found in reaction times between the Two CRT and Ten CRT with a large effect size. No condition x task interaction effect was found in reaction times. Therefore, the effect of inhibition was not stronger in one task than the other and neither inhibitory group was faster in their responses confirming the earlier analysis. The differences found in reaction times were not a result of inhibition but were purely a result of task type, with reaction time slower in the Ten CRT than in the Two CRT.

Low and high choice Go/No-go

The information presented in Table 4 shows that there was no significant difference found in reaction times between the low and high inhibitory groups. There was evidence of similar pattern to the CRT in the main effect of task type, with slower reactions in the Ten Go/No-go compared to the Two Go/No-go, however this effect only approached significance. No significant difference found in reaction times between the Two Go/No-go and Ten Go/No-go. There was no condition x task interaction effect found in reaction times. Therefore, there was no overall effect of inhibition in reaction times within the Go/No-go task however; there is evidence for approaching differences in responses purely as a result of the type of task.

Discussion

In accordance with our hypothesis, results showed that for those in the high inhibition group accuracy was enhanced but their reaction times were not affected. As no difference was found between groups in reaction times however, results failed to support the hypothesis that responses would be slower within the high inhibitory group as a consequence of greater accuracy. Although we showed that overall, those deliberately inhibited were more accurate in their responses that the control group, groups did not differ in their accuracy on either the Two-CRT, Ten-CRT or the Two-Go/No-go tasks. When results of the two CRT tasks were combined however, deliberately inhibited individuals did exceed the control group in their accuracy, making significantly less incorrect responses. While no difference was found in accuracy performance between groups on the Two Go/No-go task, a significant difference was found within the Ten Go/No-go task, with those in the high inhibitory group better at inhibiting incorrect responses than the control group. The greater distinction between groups shown in the high choice Go/No-go task than in the low choice task is consistent with the hypothesis that inhibitory effects become stronger as the number of choices increase. Reaction times were faster in the Two CRT task than in the Ten CRT task in both conditions. This is consistent with the idea that reaction time increases as a function of an increase in information (Hick, 1952). This effect was not shown however in the Go/No-go tasks where reaction times did not significantly differ between the two tasks. The finding that increased inhibition enhances accuracy on reaction time tasks provides support for neurological findings where damage caused to areas involved in the inhibitory network system impaired ability to inhibit incorrect responses (Chudasama et al, 2003; Fillimore & Rush, 2002). Results however, fail to reflect findings shown in stroop tasks of enhanced urination urgency improving reaction times (Tuk et al, 2011), as well as enhanced activity of inhibitory regions (ACC) improving reaction times (Naito et al, 2000). By revealing a difference in cognitive processing ability purely as a result of motor inhibition, this paper supports the idea that inhibition is not domain specific but can in fact, spill over into unrelated domains (Berkman et al, 2009).

This paper is the first to present direct evidence of the ISE at work on basic inhibitory mechanisms. The enhanced control in behaviour reflected in previous research on the ISE can be attributed to its influence on the cognitive processes found here. By causing self-control over accuracy at this basic level of processing, the ISE automatically restrains our behaviour in everyday situations, enabling us to avoid errors in our decision-making. This is consistent with the results found in monetary and food consumption decision-making (Tuk et al, 2011, 2012) where inhibited individuals chose the most correct option out of the choices available. In the food consumption experiment for example, an incorrect response was inferred as losing control over temptation and eating the crisps supplied. Therefore, the individuals deliberately inhibited using an attention-regulation task made less of these impulses all because they were influenced at a basic level to avoid incorrect responses. The same can be used to explain the increased intertemporal patience shown in financial decision-making, where the incorrect response of choosing the smaller amount of money was selected less frequently than in the control group. The reduction in impulsivity shown in these studies makes sense considering that at the basic level more thought seems to have been given to the decision instead of responding on impulse. The enhanced ability to control incorrect impulses also explains why the ISE has been found to improve performance in lying (Fenn et al, 2015). Considering that liars were motivated to convince others of their truth telling, an incorrect response for them would be revealing behavioural cues of deceit such as anxiousness and high cognitive demand. As we know, those inhibited showed less of these signs, which we may now argue is a result of their increased ability to avoid incorrect responses in their underlying cognitive processes. In revealing improved accuracy at this level we are able to provide explanations to the various phenomena observed as a result of inhibition. We conclude that inhibition works to benefit us in our decisions, promoting greater avoidance of incorrect choices.

While this study revealed an overall influence of the ISE in enhancing accuracy, the finding was not consistent across all four of the tasks. Within the low and high choice CRT task, little difference was found between inhibitory groups in incorrect responses. Considering that there was an overall effect of the ISE when results from both tests were combined and compared to the control group, accuracy was enhanced but not as a result of the manipulation on choices. Unlike the Go/No-go tasks, the increased number of choices available did not present a greater distinction between groups as previously hypothesised. Instead, the difference between groups was better shown in the task that had fewer choices available. This fails to reflect the theory that as the number of incorrect alternative responses increase so does the demand on inhibitory processes (Kornblum, 1965). Considering that this effect was shown in the Go/No-go tasks however, we may not put the emphasis on the lack of inhibitory processes at work but instead look to the difference in procedure between tasks. For the Go/No-go, both tasks involved the same mode of response, pressing only the spacebar, while in the CRT, the low choice task involved pressing two keys of close proximity and the high choice involved pressing a wide range of keys at varying distances from one another. The lack of difference in incorrect responses between the two inhibitory groups in the high choice CRT task may have been because the process of locating the response was much more conscious than in the low choice. By actively having to search for the number on the keypad, one makes a conscious effort of choosing the correct response, while making a response in the low choice involves a more impulsive reaction as their fingers are already hovering over the keys. This would make sense given that overall reaction times were much slower in the high choice CRT than in the high choice Go/No-go where no search was required. According to this, we may infer that the ISE enhances performance primarily when we make instinctive decisions.

The different mode of response for both tasks might also explain why only the CRT task showed results consistent with Hicks Law (1952) with response times significantly slower in the high choice than in the low choice. While reaction times between the two Go/No-go tasks reflected a similar pattern to the CRT tasks, it failed to reveal a significant increase to the same extent. With the manipulation of choices accounting for as much as 95% of the variance within CRT reaction times, this task very clearly indicates that processing speed increases with the introduction of more alternative choices. The fact that this was not replicated in the Go/No-go task does not mean that Hicks Law is redundant on such tasks but can be instead attributed to the difference in the mode of response as previously mentioned. In the high CRT, more time is required in order to locate a response while in both the low and high choice Go/No-go task, the key remains the same, thus no time spent on the search. This finding highlights a fundamental criticism of the use of reaction time tasks in measuring cognitive processes. As responses on such tasks involve carrying out a motor action, it is hard to determine whether results are due to cognitive processing speeds or the time taken to carry out the physical response (Bernal & Altman, 2009). Considering this, Hicks Law (1952) may have been greater in the CRT tasks as a result of the increased involvement of motor actions, where participants had to move their hand to achieve the response instead of just their finger.

While this paper revealed the role of the ISE as increasing accuracy in responses, it failed to show any influence on reaction times. The lack of difference found between inhibitory groups in their response speeds can be attributed to the speed-accuracy trade-off effect where accuracy was enhanced at the expense of the other (Fitts, 1954). Interestingly, the inhibited group managed to be more accurate than the control group without experiencing a significant increase in response times, contradicting our hypothesis. This finding goes against results from reaction time tasks where individuals with high inhibitory functioning (ACC activity) made faster responses at the expense of error (Mulert et al, 2003). In relation to our findings, the inhibited individuals should have been slower than the control group given the time needed to accurately process the correct responses. As no extra time was needed to process these responses, we may infer that the ISE reduces speed-accuracy trade-offs, where either one can be enhanced but not at a detrimental expense of the other. This is consistent with the results found on stroop tasks where performance is reversed (Tuk et al, 2011). While the inhibited individuals in this study had better accuracy but the same reaction times as the control, inhibited individuals on the stroop task had faster reaction times while accuracy remained the same as control. Like the results of the present study, inhibited individuals proved not as susceptible to trade-offs with the ISE enabling them to make the same amount of correct responses in less time than the control group. Although these tasks both examine the influence of the ISE on the same variables, they show the opposite effect from one another in terms of accuracy and speed. This difference between tasks may be a result of the performance motivation, with individuals on the stroop task motivated to focus more on accuracy while here; individuals put more focus on speed. As the main purpose of stroop tasks is to demonstrate how interference in cognitive processing impairs reaction time, the role of accuracy is emphasised at the expense of speed. When considering the tasks used in this study, performance did not involve interference at the cognitive level but instead involved a quick response corresponding to the stimuli, thus speed was emphasised over accuracy. This is consistent with the idea that stroop tasks examine more complex functioning than CRT tasks (Takahashi, Turek & Moore, 2001), considering that the motivation of performance on such tasks seems more cognitively demanding. In order to confirm the role of task motivation on trade-offs under the ISE, future research may manipulate instructions using a repeated measures design from emphasis on speed to emphasis on accuracy within a simple CRT task. With relation to the results from stroop tasks (Tuk et al, 2011) we may conclude that the ISE limits the effect of the speed-accuracy trade-off where enhanced performance on one does not impair the other to the same extent as it does within a normal population.

Given that this paper reveals the ISE as beneficial to performance, it is important to consider the negative impact of the ego-depletion effect (Baumeister, 2002) on the same behaviour. With reference to research examining the ISE on food consumption (Tuk et al, 2012), the after effect of inducing inhibition has been found to impair the same behaviour that was previously enhanced. Therefore, the enhanced accuracy observed at this basic level may consequently cause deterioration on the same processes post-experiment. As a means of exploring this, future research may use the same procedure as the present study but repeat the tests once the individual has emptied their bladder. If depletion does occur on these processes as a consequence of the ISE, then the role of inhibition on everyday functioning would require further analysis.

According to this study, the ISE enables greater avoidance of incorrect responses at a very basic cognitive level. By testing the ISE on a series of reaction time tasks, these findings are the first to directly confirm the assumed mechanisms underlying results found in applied settings. The observation that the ISE makes us less susceptible to incorrect responses corresponds with the idea of inhibition as a vigilance mechanism (Gray, 1972), where behaviour leading to negative consequences is avoided. The perspective that inhibition enables intelligent analyses of our environment (Sternberg & Kaufman, 2002) further relates to our findings, with inhibited individuals avoiding reacting on impulsive and instead calculating the most appropriate action. While this study supports the role of inhibition as advantageous to behaviour, further analysis is needed to better understand the consequences of such an effect once inhibitory processes are relaxed.

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