UNIVERZITA KOMENSKÉHO V BRATISLAVE
FAKULTA MATEMATIKY, FYZIKY A INFORMATIKY

INHIBITION AT THE PHYSIOLOGICAL, BEHAVIORAL, AND TRAITS LEVEL

Master's Thesis

2021 Bc. Michal Kováč

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Master's Thesis

Study Programme:	Cognitive Science
Field of Study:	Computer Science
Department:	Department of Applied Informatics
Supervisor:	RNDr. Barbora Cimrová, PhD.

Bratislava 2021 Bc. Michal Kováč

Comenius University in Bratislava
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THESIS ASSIGNMENT

Name and Surname:	Bc. Michal Kováč
Study programme:	Cognitive Science (Single degree study, master II. deg., full time form)
Field of Study:	Computer Science
Type of Thesis:	Diploma Thesis
Language of Thesis:	English
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Title: Inhibition at the physiological, behavioral, and traits level

Annotation: Inhibitory deficits are considered to constitute endophenotypes of various mental disorders (schizophrenia, OCD, depression, ADHD, addiction, etc.). Paradigms standardly used to determine behavioral and physiological markers of inhibitory processes include prepulse inhibition (PPI), the go/no-go (GNG) task, and the stop-signal task (SST). Recent findings suggest that mechanisms involved in GNG and SST (not performing a prepotent response and stopping an ongoing action) are not identical. However, their relationship to PPI is not yet known.

Aim: The aim of this thesis is to investigate the relationships between inhibitory processes at the physiological, behavioral, and the level of traits that may indicate susceptibility to psychopathology. Evaluate the potential link between the parameters of the two standard measures of cognitive inhibition (GNG and SST) and prepulse inhibition, and perform an exploratory analysis on questionnaire data (mainly impulsivity, neuroticism and schizotypia).

Literature: Bari, A., & Robbins, T. W. (2013). Inhibition and impulsivity: Behavioral and neural basis of response control. Progress in Neurobiology, 108, 44–79.
Hampshire, A. (2015). Putting the brakes on inhibitory models of frontal lobe function. NeuroImage, 113, 340-355.

Keywords: inhibition, prepulse inhibition, stop signal task, go/no-go task, psychopathology

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ZADANIE ZÁVEREČNEJ PRÁCE

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Študijný program: kognitívna veda (Jednoodborové štúdium, magisterský II. st., denná forma)
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Názov: Inhibition at the physiological, behavioral, and traits level
Inhibícia na úrovni fyziologickej, behaviorálnej a úrovni osobnostných čŕt

Anotácia: Poruchy inhibičných procesov sú považované za endofenotypy rozličných mentálnych porúch (schizofrénie, OCD, depresie, ADHD, závislosti, atď.). Medzi štandardné paradigmy využívané na stanovenie behaviorálnych a fyziologických markerov inhibičných procesov patrí prepulzná inhibícia (PPI), úloha go/no-go (GNG) a úloha stop-signál (SST). Ukazuje sa, že mechanizmy zabezpečujúce GNG a SST, teda nevykonanie prepotentnej odpovede a zastavenie už prebiehajúcej akcie nie sú totožné, no ich vzťah ku PPI zatiaľ nie je objasnený.

Cieľ: Cieľom práce je preskúmať vzťahy inhibičných procesov na úrovni fyziologickej, behaviorálnej a úrovni čŕt naznačujúcich náchylnosť na psychopatológiu. Zhodnotiť súvislosť medzi parametrami dvoch štandardných mier kognitívnej inhibície (GNG a SST) a prepulznej inhibície a vykonať exploratívnu analýzu na výstupoch z dotazníkov (najmä impulzivita, neuroticizmus a schizotypia).

Literatúra: Bari, A., & Robbins, T. W. (2013). Inhibition and impulsivity: Behavioral and neural basis of response control. Progress in Neurobiology, 108, 44–79.
Hampshire, A. (2015). Putting the brakes on inhibitory models of frontal lobe function. NeuroImage, 113, 340-355.

Kľúčové slová: inhibícia, prepulzná inhibícia, úloha stop-signal, úloha go/no-go, psychopatológia

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Acknowledgement

I would like to thank my supervisor, RNDr. Barbora Cimrová, PhD., for her help and guidance with work on this thesis. I would also like to thank MUDr. Igor Riečanský, PhD. and everyone else involved in the original project which served as a basis of this thesis, and which made it possible. Finally, I would like to thank my family, friends and peers for various forms of support they have provided.

Abstract

Inhibition is a fundamental cognitive function observable on multiple levels. It has been studied by multiple scientific disciplines. Its deficiency is linked to many serious psychiatric disorders. Despite that it is still not complexly understood. In this thesis we have decided to focus on physiological, behavioral and personality trait measures of inhibition in order to help advance the complex understanding of this phenomenon. In particular a within-subject experiment was conducted on 123 participants using prepulse inhibition (PPI) as a measure of physiological level of inhibition, go/no-go task (GNG) and stop signal task (SST) as measures of behavioral level of inhibition and NEO Five-Factor Inventory (NEO-FFI), Schizotypal Personality Questionnaire (SPQ) and Barratt Impulsiveness Scale (BIS-11) as measures of personality traits level of inhibition. Prepulse facilitation (PPF) was measured along with PPI. Analysis of the results suggests that there are no links between PPI and any of the other measures. However, we found a strong correlation between PPI and PPF and an interesting correlation between PPF and the reaction time delay in GNG. We have not discovered a correlation between the SST reaction time and the GNG reaction time; however, we did discover a correlation between the reaction time delay in GNG and the stop signal delay in SSD. No noteworthy correlations between any of the behavioral tasks and traits were discovered. However, we have discovered very strong correlations across the three traits measures we have used. Overall, our findings suggest that there is no obvious link between the studied levels. The correlation between GNG and PPF seems like a worthwhile focus for a future study and so does the lack of links between PPI and behavioral measures.

Keywords: inhibition, prepulse inhibition, stop-signal task, go/no-go task, psychopathology

Abstrakt

Inhibícia je základná kognitívna funkcia pozorovateľná na niekoľkých úrovniach. Inhibícia bola skúmaná viacerými vednými disciplínami a jej deficit je spojený s mnohými vážnymi psychiatrickými poruchami. Napriek tomu inhibícia stále nie je komplexne preštudovaná a pochopená. V tejto práci sme sa rozhodli sústrediť na fyziologické, behaviorálne a osobnostné miery inhibície s cieľom rozšíriť komplexné pochopenie tohto javu. Presnejšie bol vykonaný experiment s vnútro-subjektovým dizajnom na 123 participantoch, v ktorom bola využitá prepulzná inhibícia (PPI) ako miera fyziologickej úrovne inhibície, go/no-go task (GNG) a stop signal task (SST) ako miery behaviorálnej úrovne inhibície a NEO Five-Factor Inventory (NEO-FFI), Schizotypal Personality Questionnaire (SPQ) a Barratt Impulsiveness Scale (BIS-11) ako miery inhibície na úrovni osobnostných čŕt. Spolu s PPI bola meraná aj prepulzná facilitácia (PPF). Analýza výsledkov neodhalila žiadnu spojitosť medzi PPI a ľubovoľnou inou meranou mierou inhibície. Avšak, odhalila koreláciu medzi PPI a PPF a zaujímavú koreláciu medzi PPF a oneskorením reakčného času v GNG. Neodhalili sme koreláciu medzi reakčným časom v GNG a reakčným časom v SST, ale odhalili sme koreláciu medzi oneskorením reakčného času v GNG a oneskorením stop signálu v SST. Neodhalili sme žiadne zmienky hodné korelácie medzi behaviorálnymi mierami a nami pozorovanými črtami. Medzi pozorovanými črtami sme však našli mnoho veľmi silných korelácií. Naše výsledky teda napovedajú, že medzi pozorovanými úrovňami inhibície, nie sú žiadne očividné spojitosti. Korelácia medzi GNG a PPF vyzerá ako objekt hodný ďalšieho skúmania a rovnako aj chýbajúce spojitosti medzi PPI a behaviorálnymi mierami.

Kľúčové slová: inhibícia, prepulzná inhibícia, stop signal task, go/no-go task, psychopatológia

Contents

Introduction

This thesis aims to shed more light on the details of broad concept of inhibition in cognitive science. First, a quick review of the current state of the art of inhibition research is presented. Based on this information we come up with hypotheses focused on linking different measures of inhibition. To test the hypotheses, we cooperated with a research group formed by scientists from Department of Behavioral Neuroscience, Centre of Experimental Medicine, Slovak Academy of Sciences and SCAN-Unit, University of Vienna and utilized their already existing empirical study in this domain. The whole process is documented in this thesis and the results are discussed at the end.

Inhibition is a fundamental cognitive function (Bari & Robbins, 2013). It enables humans and other species alike to cancel out unwanted thoughts and actions. Depending on the stimuli this can result into a wide range of outcomes including the ability to concentrate by inhibiting distracting stimuli or the ability to stop an execution of an action. Unsurprisingly, the impairment or deficit of inhibition is linked with many psychiatric disorders such as obsessive compulsive disorder (OCD) (Chamberlain et al., 2005), attention deficit hyperactivity disorder (ADHD) (Engelhardt et al., 2008) and schizophrenia (D. Braff et al., 1978), just to name a few. Inhibition can be observed on multiple levels including physiological (e.g., prepulse inhibition), behavioral (e.g., go/no-go task, stop signal task and Iowa gambling task) and level of personality traits (e.g., Big Five trait of neuroticism, schizotypal traits and impulsive personality traits).

Inhibition has been studied for a long time now by scientific communities utilizing many different disciplines including philosophy, psychology and neuroscience. However, the research was done in a very narrow way concentrating on only one particular part of inhibition or level on which inhibition can be observed.

We have decided to focus on this topic because inhibition undoubtedly plays a very important role in human cognitive functioning and a complex understanding of this phenomenon has potentially large implications for the scientific knowledge in the domain of cognitive science and the domain of psychiatry which could in turn have practical impacts on both the individuals affected by psychiatric disorders and the society. Therefore, our goal was to help connect multiple independent in-depth focused branches of research by doing an in-breadth study.

1 Theoretical part

In this chapter we give an introduction to the domain of inhibition, its history, how it is observable on different levels and the subdomain of its measures. We also take a look at personality models and traits relevant for this thesis.

1.1 Inhibition in general

Inhibition is a concept with a long history spanning across multiple scientific disciplines. The first discipline to study this phenomenon was philosophy. In philosophy inhibition is deeply rooted in the question of free will. In his final philosophical treatise, *The Passions of the Soul*, completed in 1649, Descartes wrote that "*if anger makes the hand rise in order to strike, the will can ordinarily restrain it; if fear incites the legs to flee, the will can stop them*" (Descartes, 1989, p. 44). This idea is close to the psychological concept of inhibition and even its behavioral measures which are discussed in chapters 1.3.1 Go/no-go task and 1.3.2 Stop signal task. Early models of inhibition in psychology were developed by Sigmund Freud. He built his models on a premise that inhibition is not just a passive ignorance of unwanted thoughts and behaviors but an active energy-requiring suppression process (Dempster & Corkill, 1999). Neurological studies done much later suggest that this premise is correct (Aron, 2007). Currently inhibition is considered to be a fundamental cognitive function by modern neuroscience (Bari & Robbins, 2013). After psychological studies of inhibition started it was soon discovered that its deficit can be used in psychiatry as a characteristic of multiple mental disorders. In particular it is now linked with obsessive compulsive disorder (OCD) (Chamberlain et al., 2005), attention deficit hyperactivity disorder (ADHD) (Engelhardt et al., 2008), schizophrenia (D. Braff et al., 1978), Gilles de la Tourette syndrome[1] (GTS) (Kohl et al., 2013), addiction (Smith et al., 2014), depression (Joormann et al., 2007) and related suicidal behavior (Richard-Devantoy et al., 2012), temporal lobe epilepsy with psychosis and enuresis[2] (D. L. Braff et al., 2001). A brief overview of papers of large significance in history of the domain of inhibition can be found in Figure 1.

[1] Gilles de la Tourette syndrome is a disorder characterized by motor and phonic tics
[2] enuresis is the inability to control urination

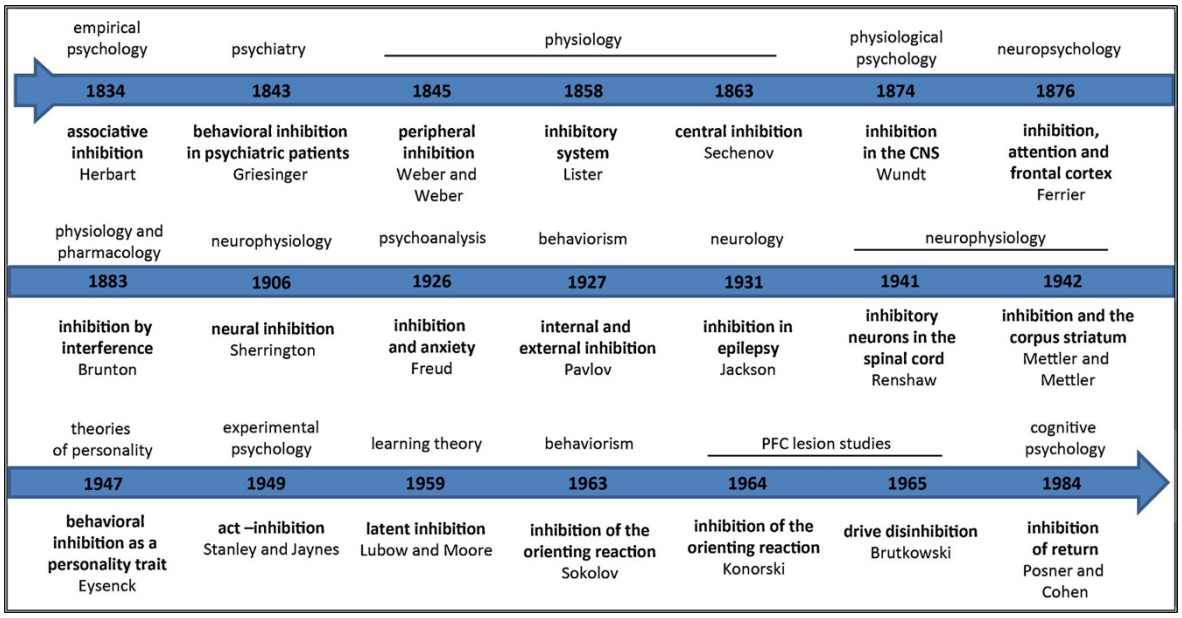

Figure 1: Timeline of most significant publications regarding inhibition (Bari & Robbins, 2013)

In both cognitive neuroscience and psychology the broad construct of inhibition is often reduced to its most simply observable component which is its behavioral manifestation. In neuroscience the focus of research has been mostly on finding its locus in the nervous system. Complete and detailed map of its neural correlates has not been established yet but majority of studies show that the common correlates are in the pre-supplementary motor area and anterior insula or in general, in the frontal lobe (Swick et al., 2011). A visual map based on an analysis of 66 neuroimaging papers and created using Activation Likelihood Estimate (ALE) algorithm can be found in Figure 2.

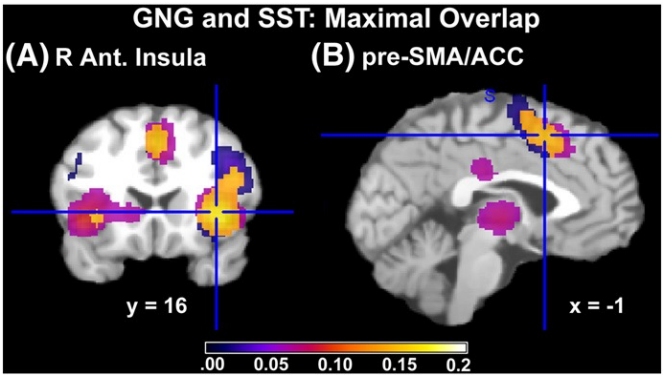

Figure 2: Regions with highest common activation in behavioral inhibition measures. "The scale bar (in arbitrary units) represents values of the ALE statistic from 0 to 0.05 (purple-blue) for voxels found in the GNG map only (purple-blue), from 0.05 to 0.1 for voxels in SST only (pink-red), and from 0.1 to 0.2 for voxels common to both maps (orange-yellow)." (Swick et al., 2011)

The behavioral measures can be done in either a cognitive or a motor variant. The cognitive variant involves no physical actions from the participants because the actions required for the task (e.g., counting) are done in the participant's mind. The motor variant is evaluated based on physical actions (e.g., button presses). However, the results of both variants have proven to have strong correlation and investigation of event-related potentials (ERPs) revealed that the components of both variants are similar (Smith et al., 2013; Bruin, 2002). In research the motor variant is used more often since it offers practical advantages.

Various cross-species inhibition studies were conducted and remarkable consistency was found across species in both translation of observed results and neural correlates (D. L. Braff et al., 2001; Eagle et al., 2008). This has been greatly utilized in studying neurobiological basis of behavioral inhibition and impulsivity (Bari & Robbins, 2013). The experiment in this thesis, described in detail in chapter 2.2 Methods, was done on human participants but findings from other species were considered in this chapter and chapter 2.4 Discussio.

Interdisciplinarity of this domain is already clear from this brief overview. However, most of the research done strictly focuses on one particular scientific discipline. A comprehensive review paper by Andrea Bari and Trevor W. Robbins (Bari & Robbins, 2013) mentions an issue stemming from this fact. The terminology in the inhibition domain in between disciplines is not consistent. This hinders exchange of ideas, observations and findings in between the different but related scientific communities, a consequence of which is a negative feedback loop making this issue progressively worse.

1.2 Prepulse inhibition and facilitation

Prepulse inhibition (PPI) is a neurological phenomenon on a physiological level that causes decreased response to a startling stimulus (main pulse) if it is shortly preceded by a weaker startling stimulus (prepulse) (Larrauri & Schmajuk, 2006). Different modalities of a prepulse and a main pulse can be used – for example acoustic, cutaneous or visual (D. L. Braff et al., 2001). The modalities of a prepulse and a main pulse can even differ (e.g., a visual prepulse and an auditory main pulse) or be used in conjunction (e.g., visual and auditory pulses at the same time) (Larrauri & Schmajuk, 2006). The strength of the effect on the startle response is dependent on multiple parameters with the delay between the prepulse and the main pulse being most significant (D. L. Braff et al., 2001). The peak inhibition is achieved with main pulse delay of around 100 ms. If the main pulse delay is too short (bellow 30 ms) or too long

(above 500 ms) an opposite effect of increased startle response happens (Larrauri & Schmajuk, 2006). This effect is called prepulse facilitation (PPF) (Larrauri & Schmajuk, 2006). The differences between baseline startle response, prepulse inhibition and prepulse facilitation are explained in Figure 3.

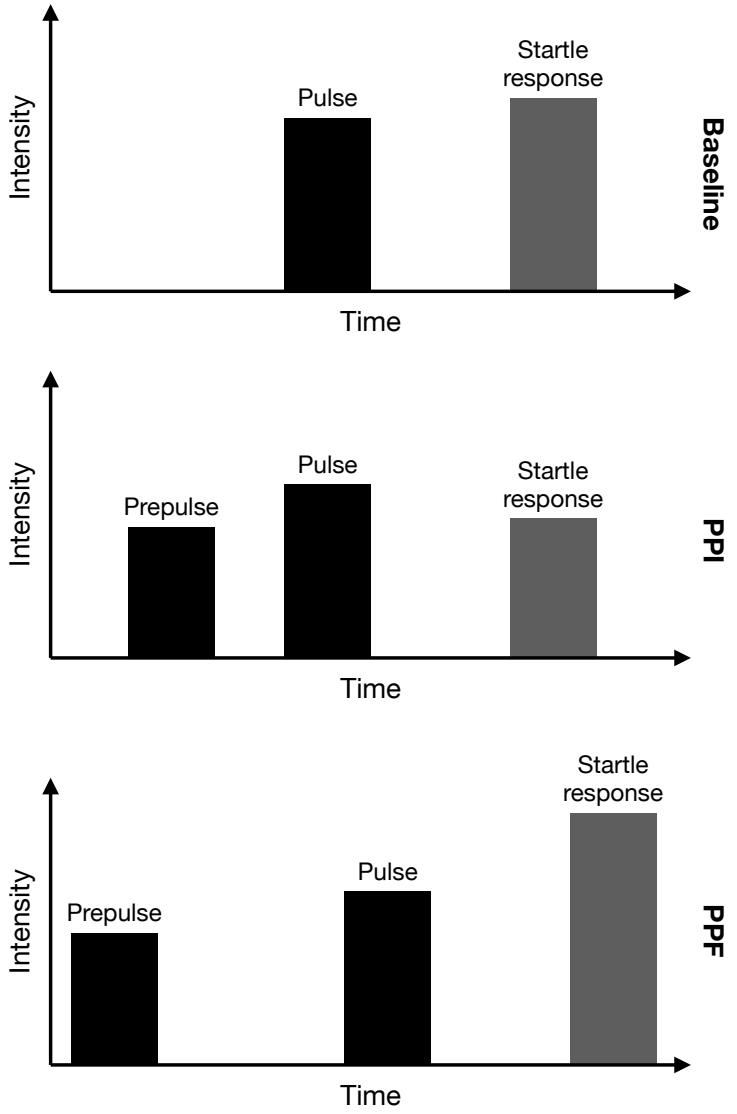

Figure 3: Diagram of PPI and PPF compared to baseline startle response. Please note that certain abstraction is necessary when reading this diagram since units of intensity are different for pulses (decibels) and response (typically microvolts measured by electromyograph).

Other parameters affecting the strength of the effect of PPI and PPF are background noise level, prepulse intensity, main pulse intensity, prepulse duration and main pulse duration (Larrauri & Schmajuk, 2006). If startle stimulus is delivered along with another stimulus

with negative association (e.g., electric shock), the startle response is increased (Larrauri & Schmajuk, 2006). This is called response potentiation (Larrauri & Schmajuk, 2006). Opposite effect called response attenuation happens when the accompanying stimulus has a positive association (e.g., food) (Larrauri & Schmajuk, 2006).

PPI is considered to measure a process called sensorimotor gating (D. L. Braff et al., 2001). Sensorimotor gating serves to filter stimuli that are not important out of awareness so that an individual can focus on more important parts of the environment (D. L. Braff et al., 2001).

In humans PPI and PPF is typically measured using the eye blink component of the startle reflex (Kohl et al., 2013). Acoustic stimuli are usually selected as a modality of both a prepulse and a main pulse (Kohl et al., 2013). PPI or PPF value is calculated using a main pulse alone measurement (PA) as the baseline level and a prepulse followed by the main pulse measurement (PP) as the manipulated level. The primary outcome of PPI or PPF measurement is a percentual value of change of the level of startle response calculated using the following formula (Kohl et al., 2013):

$$PPI\ (\%)\ = \frac{PA - PP}{PA} * 100$$

Response latency and habituation rate can be reported as well. If acoustic stimuli are used the prepulse levels are typically 4 dB to 16 dB higher compared to the background noise and the main pulse is usually set to 105 dB to 115 dB level (Leumann et al., 2001).

PPI has multiple practical advantages that make it appealing for research. It translates well between species (D. L. Braff et al., 2001). It is not very demanding of participants – minimal compliance and low motivation is sufficient (Kohl et al., 2013). It occurs in a robust and predictable manner (D. L. Braff et al., 2001). It is sensitive to sensory, cognitive and pharmacological manipulations (Kohl et al., 2013).

PPI deficiency is linked with various mental disorders. The most widely associated one is schizophrenia which is supported by substantial evidence (Kohl et al., 2013). Because of this PPI deficiency is considered to be a biomarker of schizophrenia (Mena et al., 2016). OCD, Gilles de la Tourette syndrome (GTS) and bipolar disorder (BD) while in manic episodes have been studied as well and multiple links were found but the evidence is not sufficient to draw conclusions yet (Kohl et al., 2013).

1.3 Behavioral measures of inhibition

Behavioral measures of inhibition are typically based on observing response inhibition (Criaud & Boulinguez, 2013). Response inhibition (sometimes also called action inhibition) is an executive function that allows suppression of prepotent responses (Bari & Robbins, 2013; Diamond, 2013). Just a decade ago action inhibition was further split into two types (Eagle et al., 2008). First type is action restraint (Schachar et al., 2007). Action restraint is inhibition of response tendency, i.e., inhibition of an action before its execution even starts (Schachar et al., 2007). Second type is action cancellation (Schachar et al., 2007). Action cancelation is inhibition of an ongoing action, i.e., inhibition of an action while it is being executed (Schachar et al., 2007). In this subchapter we discuss two most popular measures of action inhibition – go/no-go task and stop signal task (Eagle et al., 2008). For a long time go/no-go task and stop signal task were considered to be equivalent measures of response inhibition and they were used interchangeably (Verbruggen & Logan, 2008a). In the following subchapters the subtle differences are explained.

1.3.1 Go/no-go task

In go/no-go task (GNG) action restraint is measured by instructing the participant to do an action (go) or to avoid doing it (no-go) based on what target is presented. The target is unpredictable. In studies on humans, visual stimulus is usually used to present the target (Wright et al., 2014). A motor action (e.g., button press) is typically used to evaluate the outcome of a trial (Bari & Robbins, 2013). Nowadays the task is usually done on a computer with a monitor used to present the target and keyboard used to register the motor action or lack thereof.

Typically evaluated dependent variable in GNG is percentage of false alarms and reaction time (RT) in go trials (Eagle et al., 2008). The independent variables are the frequency of go targets and trial duration (the time between stimuli) (Wessel, 2018).

A fairly recent discovery is that the representations of targets can be memorized after repeated trials which means that action restraint is no longer needed to successfully complete the task since there is no prepotent response but an appropriate response is selected directly by memory retrieval (Verbruggen & Logan, 2008a). There are multiple ways to attempt to mitigate this. The simplest solution is to change the target representations after a set number of trials (e.g., go targets are represented by animals and no-go targets are represented by

plants, with the particular animal/plant changing in every trial) (Verbruggen & Logan, 2008a).

A cued variant of the GNG tries to mitigate the same issue in a different way. Shortly before showing the real target a cue suggesting what the target is going to be is presented. However, in some trials the cue is invalid. This adds two independent variables to the experiment – frequency of invalid cues and the duration for which the cue is displayed. The critical condition is a go cue and a no-go target which pre-primes the participant making him/her prepare the prepotent response and then requires him/her to inhibit it (Huster et al., 2013). In a way this makes the GNG more similar to the stop signal task (described in detail in subchapter 1.3.2 Stop signal task) since the measure is not purely about action restraint anymore. The participant is pre-primed for the execution of one of the two actions which makes the action inhibition required to be similar to both action restraint and action cancellation.

1.3.2 Stop signal task

Stop signal task (SST) measures action cancellation by instructing the participant to complete a simple task (e.g., press a left button if a left arrow is presented and a right button if a right arrow is presented) but inhibit the response if a stop signal is presented (Verbruggen et al., 2019). Stop signal is presented in minority of trials (Verbruggen et al., 2019). In humans a visual go signal and an auditory stop signal is typically used (Schachar et al., 2007). The stop signal is presented after certain stop signal delay (SSD) (Verbruggen et al., 2019). In a typically used variant the SSD is variable and adjusts based on the performance of the participant – decreases after failed trials (making the task easier) and increasing after successful trials (making the task harder). SST can and has been used by various scientific disciplines (see panel A of Figure 4) and across various human and non-human populations (Verbruggen et al., 2019). The flexibility and simplicity make it a very popular if not the most popular paradigm for measuring response inhibition (see panel B of Figure 4) (Verbruggen et al., 2019). Generally it is also considered to be one of the most efficient and direct paradigms for measuring response inhibition (Schall et al., 2017; Verbruggen & Logan, 2008b).

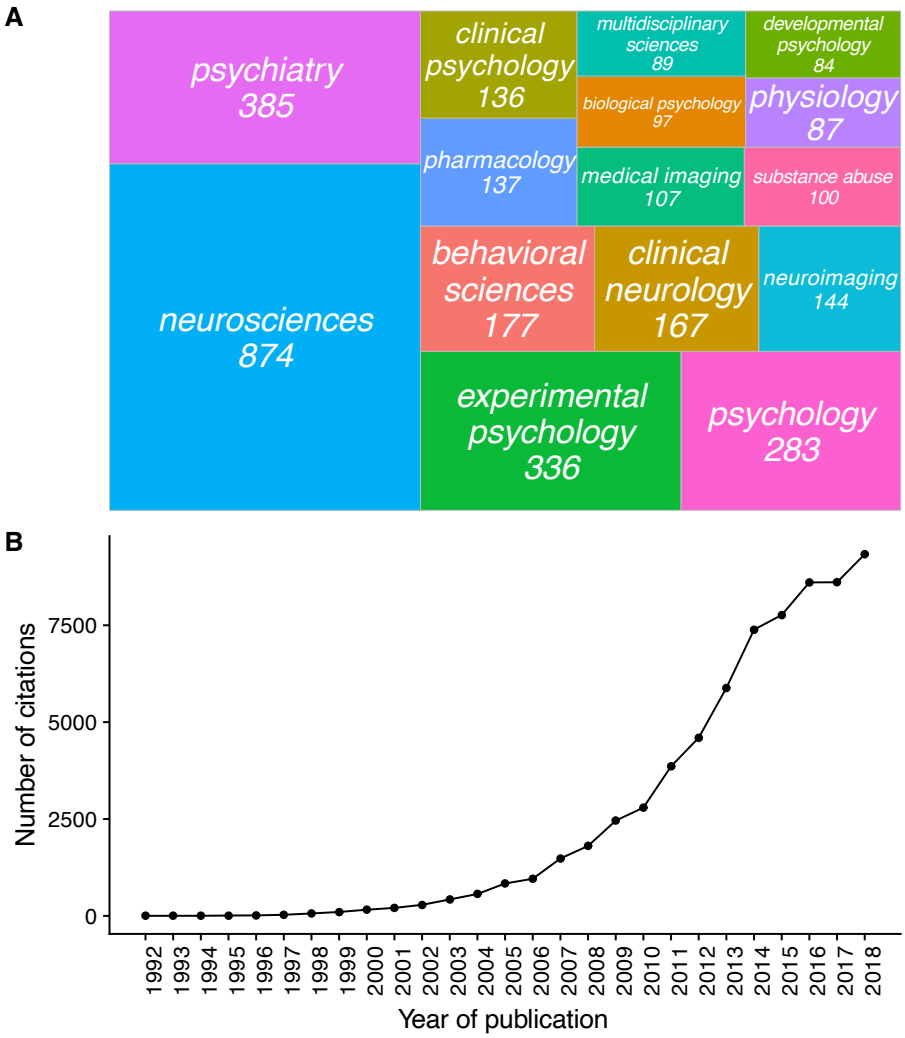

Figure 4: Diagram with absolute number of publications citing stop signal task Panel A: per scientific (sub)discipline and Panel B: per calendar year. Data as of beginning of 2019, search term "topic = stop signal task", taken from (Verbruggen et al., 2019).

A prominent model of SST performance is called an independent race model. Its name is derived from the basic idea that models SST as a race between a go process (started by a go signal) and a stop process (started by a stop signal) (Logan & Cowan, 1984). Whichever process finishes first decides the result. If the go process finishes first the action is executed (Logan & Cowan, 1984). If the stop process is finished first the action is inhibited (Logan & Cowan, 1984). A big advantage of the independent race model is that it allows estimation of the response inhibition latency which is not directly observable (Verbruggen et al., 2019). For this estimation to be accurate the error rate has to be close to 0.50 which is why variable SSD, creating a closed loop, is usually used (Verbruggen et al., 2019). Multiple models

doubting or building on the independent race model were published since it was published but it still holds as a golden standard in SST research (Verbruggen & Logan, 2017).

The independent variables of SST are initial SSD and the function by which it is adjusted in between trials, share of stop trials, the difficulty of the go task and the duration/variability of the intertrial interval (ITI) (Verbruggen et al., 2019). A diagram of the SST procedure with some of these variables represented is in Figure 5. The directly observable dependent variables of SST are RT in go trials, mean SSD and share of unsuccessful trials (Verbruggen et al., 2019). As was already previously mentioned, response inhibition latency is not directly observable (since it results into a lack of observable response) however its estimation is an important dependent variable as well (Verbruggen et al., 2019). The estimation is usually referred to as stop signal reaction time (SSRT) and can be calculated using an integration method or a mean method provided by the independent race model explained above (Logan & Cowan, 1984).

Mean method is based on an assumption that the mean SSD summed up with the mean SSRT is equal to the mean RT. For this assumption to be correct the probability of reacting in a stop trial has to be 0.50, which, as was already mentioned, can be achieved by using variable SSD. The SSRT can then be calculated as:

$$SSRT = \overline{RT} - \overline{SSD}$$

Integration method is based on integrating the RT distribution function and finding at which point the integral is equal to the probability of reacting in a stop signal trial. The finishing time of the inhibitory process is equal to the nth RT in the distribution of all go trials, n = number of all go trials multiplied by the probability of reacting in a stop signal trial. For example, in case of 150 go trials and with probability of reacting in a stop signal trial of 0.46, the nth RT is the 69th fastest go RT. SSRT is then estimated as:

$$SSRT = RT_n - \overline{SSD}$$

These calculation procedure descriptions are based on the race model originally developed by Logan & Cowan (1984) as described by Verbruggen et al. (2019).

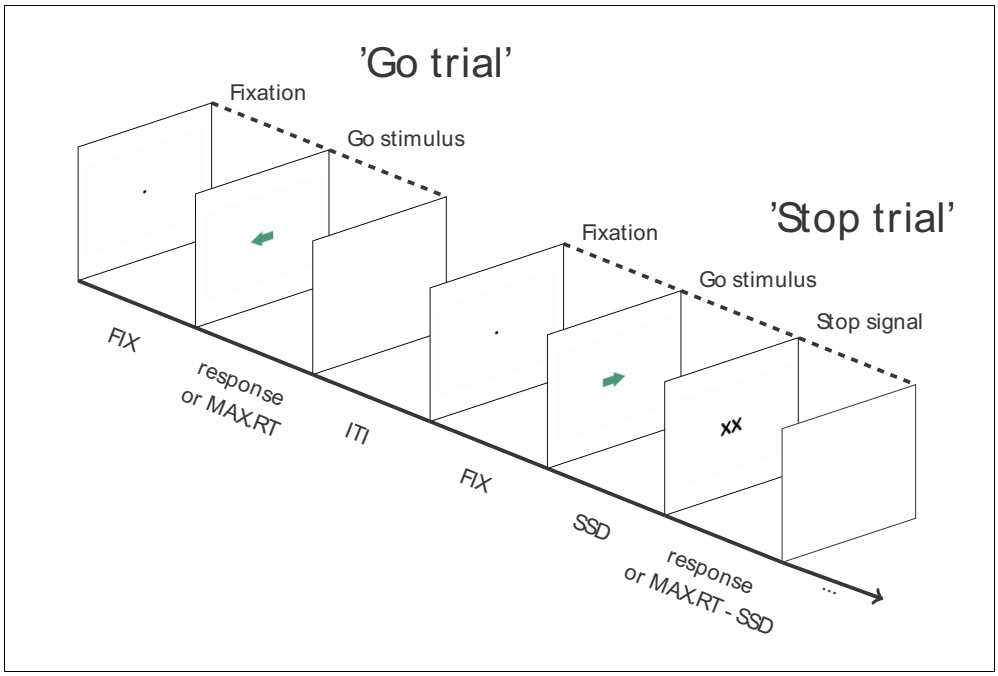

Figure 5: Diagram of SST trial procedure with labeled variables. Taken from Verbruggen et al. (2019).

A variant of SST that measures action restraint instead of action cancellation exists as well. In this variant the stop signal always occurs concurrently with the go signal – i.e. the SSD is 0 ms (Schachar et al., 2007). It has been utilized for a direct comparison of action cancellation and action restraint within the same group (Schachar et al., 2007). Otherwise, to the best of our knowledge this variant offers no advantages over GNG. Another variant of SST is called anticipatory response variant. Anticipatory response variant of the SST is promising but it is rarely used (Verbruggen et al., 2019). For its task it utilizes a moving indicator which needs to be stopped by the participant when it reaches a particular stationary target (Verbruggen et al., 2019).

1.4 Personality

Personality is naturally understood and discussed by humans (Corr & Matthews, 2009). However, the descriptions in natural language usually do not even attempt to capture the whole personality but rather they capture one particular trait in an analogical way (Matz et al., 2016). In science a complete picture is required and there are multiple approaches of how we can attempt to capture it (Matz et al., 2016). The theories of personality range from biological paradigm, behavioral paradigm, psychoanalytic paradigm to social-cognitive

paradigm (Corr & Matthews, 2009). However, by far the most used paradigm is a trait one (Matz et al., 2016; Raad & Barelds, 2020). This applies to an extent that the other paradigms are often only briefly mentioned in review papers and handbooks (Matz et al., 2016; Raad & Barelds, 2020). Trait paradigm is based on observing personality using complex questionnaires and obtaining the most critical factors (Matz et al., 2016). The trait paradigm is perfectly suitable for this thesis as well.

The trait theories date back to the Greek physician Hippocrates (ca. 460–370 BCE) and the theory of the four humors which were believed to be a balanced system determining one's health and also one's temperament and behavior (Corr & Matthews, 2009). Modern trait theories were introduced in 20th century (Matz et al., 2016). Allport's trait theory is based on categorization of almost 18 000 dictionary words that could be used to describe humans (Matz et al., 2016). These words were categorized into four categories, one of which is personality traits (Matz et al., 2016). This laid a foundation for some of the most prominent modern theories including Cattell's 16 Factor Model which then led to the development of the Big Five (Matz et al., 2016). Another noteworthy personality theory is Eysenck's Giant Three which consists of three orthogonal factors (extroversion, neuroticism and psychoticism) which form a three-dimensional personality space (Corr & Matthews, 2009). Eysenck put a lot of effort into systematic investigation of biological correlates of personality traits which was an important contribution to the domain (Matz et al., 2016).

The Big Five model is a trait theory that uses five independent traits to capture personality (Matz et al., 2016). The traits it defines are openness to experience, conscientiousness, extroversion, agreeableness and neuroticism (Corr & Matthews, 2009). These traits are further broken down into facets listed in Table 1. Openness to experience represents whether the person prefers novelty or convention (Matz et al., 2016). Conscientiousness represents whether the person prefers organized or flexible approach in life (Matz et al., 2016). Extroversion represents whether the person enjoys company of others and seeks excitement (Matz et al., 2016). Agreeableness represents whether the person lives in a social harmony and is easy to cooperate with (Matz et al., 2016). Finally, neuroticism represents whether the person has a tendency to experience negative emotions and feelings (Matz et al., 2016).

Trait	Facets
Openness to experience	Fantasy
	Aesthetics
	Feelings
	Actions
	Ideas
	Values
Conscientiousness	Competence
	Order
	Dutifulness
	Achievement-striving
	Self-discipline
	Deliberation
Extroversion	Warmth
	Gregariousness
	Assertiveness
	Activity
	Excitement-seeking
	Positive emotions
Agreeableness	Trust
	Straightforwardness
	Altruism
	Compliance
	Modesty
	Tendermindedness
Neuroticism	Anxiety
	Angry hostility
	Depression
	Self-consciousness
	Impulsivity
	Vulnerability

Table 1: The Big Five traits and facets

A self-report questionnaire is used to observe the personality and is evaluated into a score on a scale for each trait and facet (Matz et al., 2016). The typically used questionnaires are International Personality Item Pool (IPIP), the Big Five Inventory (BFI) and NEO-Personality Inventory Revised (NEO-PI-R) (Matz et al., 2016). In these questionnaires participants indicate whether they agree with a statement (e.g., "I get stressed easily") or not using a five-point Likert scale (Matz et al., 2016). The scores can be used to compare participants in a given sample but are not telling on their own (Corr & Matthews, 2009).

At its core neuroticism is believed to be a tendency to experience negative emotions. These emotions include anxiety, fear, sadness, anger and irritability (Jeronimus et al., 2016). Higher than normal neuroticism scores are strongly linked with common mental disorders (Jeronimus et al., 2016). Neuroticism is also linked with cognitive-perceptual and affect regulations problems (Jeronimus et al., 2016). Currently there is no consensus on what model explains this link most accurately (Ormel et al., 2013). The proposed models are vulnerability model (i.e., neuroticism starts processes that lead to psychiatric disorders), spectrum model (i.e., neuroticism and psychiatric disorders are manifestations of the same process), common cause model (i.e., neuroticism and psychiatric disorders share determinants) and state and scar models (psychiatric disorder episodes add temporary or permanent neuroticism) (Ormel et al., 2013). As was previously discussed these psychiatric disorders are in turn linked with deficiency of inhibition. Depending on which model represents the reality the best it could be hypothesized that deficiency of inhibition is linked with neuroticism as well. That is why out of the Big Five traits, neuroticism is of particular interest for this study.

1.5 Schizotypy

Schizotypy is a concept that defines a continuum of personality characteristics related to psychosis and schizophrenia in particular (Barron et al., 2018). A general consensus is that schizotypy expression is multidimensional (Barron et al., 2018). However, the particular number of dimensions is still being debated (Barron et al., 2018). Schizotypic traits can cause deficits in cognition, socio-emotional function and behavior (Barron et al., 2018). These traits put a person on the schizophrenia spectrum (schizotypal personality disorder) but on their own they are not enough to classify a person as schizophrenic (Fonseca-Pedrero et al., 2018). Schizophrenia is also associated with increased trait of impulsivity (see 1.6 Impulsivity). Schizophrenia is diagnosed by evaluating symptoms defined in Diagnostic and

Statistical Manual (DSM-III-R; Spitzer, 1989). A well-established measure that assesses schizotypal personality traits aligned with this manual is Schizotypal Personality Questionnaire (SPQ) (Barron et al., 2018). SPQ has a scale for each of the nine symptoms of schizotypal personality disorder (STPD) (Barron et al., 2018). The symptoms are no close friends, constricted affect, ideas of reference, odd beliefs and magical thinking, unusual perceptual experiences, odd or eccentric behavior, odd speech, suspiciousness, and excessive social anxiety (Raine, 1991). SPQ has been translated into a number of languages and it is the leading measurement for schizotypal research (Barron et al., 2018).

Rates of schizotypal personality disorder are significantly higher in relatives of schizophrenic people compared to people with no schizophrenic relatives (Subotnik et al., 2008). As discussed in subchapter 1.2 Prepulse inhibition and facilitation, PPI deficit is linked with STPD. PPI is also affected in relatives of schizophrenic people which is in line with findings of studies using diagnostic methods mentioned above (Cadenhead et al., 2000; Kumari et al., 2005).

1.6 Impulsivity

There are many definitions of impulsivity (sometimes also called impulsiveness). It has been defined as inability to withhold or stop a response or a thought despite of negative consequences, as a preference for a small immediate reward instead of a larger but delayed one, as acting without thinking something through or before all inputs are even available, or as novelty-seeking and an inclination to engage in risky behaviors (Bari & Robbins, 2013). However, some of these definitions seem to define unrelated behavior e.g., not being able to stop a response and consciously planning a risky activity. It seems like two types of impulsive behavior exist (Bari & Robbins, 2013). Multiple pairs of names are used for those two types, e.g., top-down and bottom-up (Bari & Robbins, 2013).

Two factors seem to be necessary for impulsive behavior – dysfunctional inhibitory process and strong impulses (Bari & Robbins, 2013). Impulsivity may negatively affect the career and social relationships in adulthood (Bari & Robbins, 2013). Impulsive traits characterize psychiatric conditions such as attention deficit hyperactivity disorder (ADHD), drug addiction and schizophrenia (Bari & Robbins, 2013). This type of impulsivity is called dysfunctional by Dickman (1990). On the other hand, a concept of functional impulsivity says that impulsivity can offer adaptive advantages and can serve to find novel solutions to

problems (Dickman, 1990). In general, impulsive individuals have superior performance in situations which require a fast reaction or in easy-to-solve problems (Dickman, 1990).

Impulsivity can be measured by either self-report questionnaires or by behavioral tasks (Bari & Robbins, 2013). The commonly used questionnaires are Eysenck Impulsiveness Questionnaire (I7; Eysenck & Eysenck, 1978) and Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995). The commonly used behavioral tasks are GNG, SST, delay-discounting task (DDT) and balloon analog risk task (BART). However, impulsive traits measured by self-report questionnaire often do not correlate with behavioral measures of impulsivity (Bari & Robbins, 2013; Jauregi et al., 2018; Reynolds et al., 2006; Stanford et al., 2009). Even various self-report questionnaires often do not intercorrelate because of the lack of the conceptual clarity in the domain of impulsivity (Parker & Bagby, 1997).

BIS-11 is used in both research and clinical settings. Strong correlations between BIS-11 subscales are known. High scores on BIS-11 scale are linked with many psychiatric disorders including addiction, bipolar disorder, ADHD and people that have attempted suicide. (Stanford et al., 2009)

2 Empirical part

This chapter documents the experimental part of the thesis. First, goals are formulated and stated. Then the methods utilized to accomplish them are described. Results of the experiment are explained next. Finally, the results are discussed, limitations are listed and ideas for future studies are proposed.

2.1 Goals

In this subchapter we discuss the aim and goals of this thesis. We explain the motivation and set out the expectations. The first subchapter, 2.1.1 Aim and motivation, explains how the work done in this thesis relates to the current state of the art in the domain. In the second subchapter, 2.1.2 Research questions and hypotheses, we lay out the particular questions we aimed to answer and hypothesis we wanted to test.

2.1.1 Aim and motivation

As discussed in chapter 1 Theoretical part, inhibition is a fundamental cognitive function necessary for normal cognitive functioning and a deficiency of which is linked with many psychiatric conditions. There are multiple levels on which inhibition can be observed. For most of those levels a standard measure exists and can be used to evaluate a level of inhibition an individual is capable of. Our theoretical review shows that links between some of the measures have already been studied and are understood, some have been studied but are not sufficiently understood yet and some have not been studied at all yet (particular links are discussed in the next paragraph). Even if the links were studied usually only two measures or levels were compared within one study. That is why we have decided to focus on three levels evaluated by multiple measures. In particular we have chosen physiological measures: PPI and PPF; behavioral measures: GNG and SST; and measures of personality traits based on self-report questionnaires: NEO-FFI, SPQ and BIS-11.

A link between GNG and SST was previously studied and both measures are known to typically yield similar results. However, in specific conditions the results differ. From the standpoint of neural correlates these two measures differ as well. The links between the behavioral measures and personality traits we have decided to focus on have been previously studied as well and it was found that the traits often do not reflect the outcomes of the behavioral measures. PPI is linked with schizotypal traits, and they are both used for the purpose of diagnosing the same disorders. To the best of our knowledge the links between

PPI and behavioral measures have not been studied yet. More details can be found in chapter 1 Theoretical part.

Therefore, the motivation and aim are to critically evaluate links between three different levels of inhibition. To the best of our knowledge a study with this many measures on this range of levels has not been previously conducted.

2.1.2 Research questions and hypotheses

The main research question is whether there are links between different levels at which inhibition can be observed. We are interested both in generalized findings and concrete links between particular measures. Links between PPI and behavioral measures are of special interest since they are unexplored.

Based on the overview of the domain we came up with the following hypotheses:

1. There is a correlation between PPI and personality traits typical for schizophrenia.
2. There is a correlation between GNG and SST.
3. There are no major correlations between behavioral measures and personality traits.
4. There is no correlation between PPI and behavioral measures.

2.2 Methods

This thesis is built on data already acquired as a part of a larger research project conducted by Department of Behavioral Neuroscience, Centre of Experimental Medicine, Slovak Academy of Sciences and SCAN-Unit, University of Vienna. In this chapter the experiment design is thoroughly described and explained.

2.2.1 Sample

The experiment was conducted on 123 participants. Split of participants by sex was evenly balanced. Participants were young people with mean age of ~23 years. Secondary education was the highest obtained education at the time of the experiment for most participants. Around two thirds of the participants were non-smokers. Exclusion criteria included diagnosed mental illness, long-term pharmacological treatment, drug abuse, left-handedness, conditions that would not permit doing the measurements (e.g., dermatitis in the head area) and auditory deficits. More detailed description of the research sample is available in Table 2. Participants were finically compensated for participating in the study.

Number of participants	Sex	Mean age	Age range	Education	Smoking
123	65F/58M	23.0	18 - 33	Primary 1, Secondary 106, Tertiary 16	48Y/75N

Table 2: Detailed description of the experiment sample

2.2.2 Procedure

A within-subject experiment design was utilized. In the beginning the participants were introduced to the experiment procedure. They signed the informed consent and were tested for exclusion criteria (see 2.2.1 Sample). Measurement of behavioral tasks, GNG and SST, in random order, followed. Since prepulse inhibition and facilitation was measured using electromyography the electrodes for this measurement were applied next. Prepulse inhibition

and facilitation were measured in one combined session lasting 25 minutes. In the end the traits questionnaires for personality, schizotypy and impulsivity assessments were conducted. The diagram of the whole procedure can be found in Figure 6.

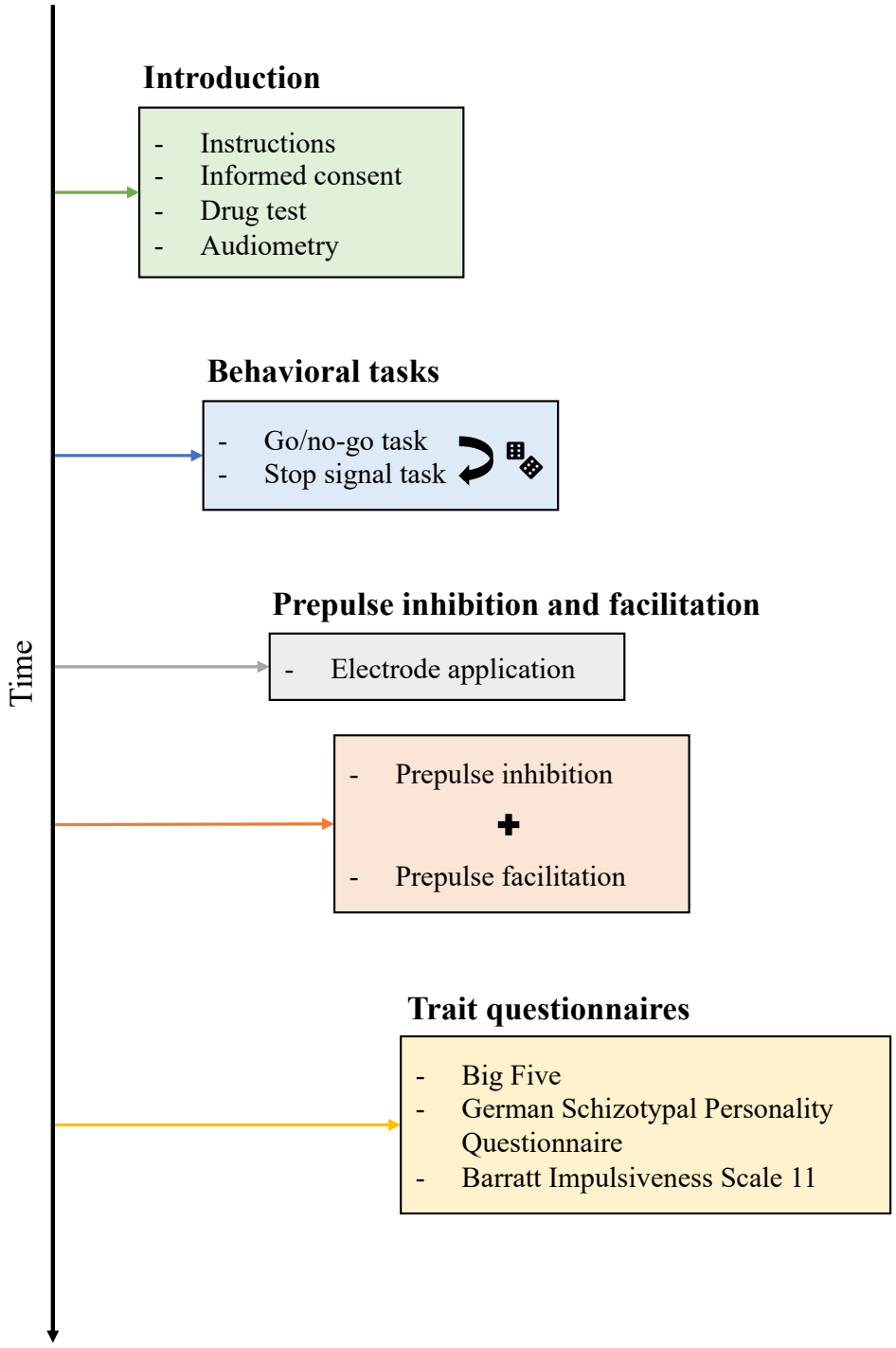

Figure 6: Experiment procedure diagram

2.2.3 Prepulse inhibition and facilitation

An auditory stimulus was used as a pulse. White noise at 55 dB was used as a background. Prepulse lasted for 20 ms at the level of 75 dB. Main pulse lasted for 40 ms at the level of 104 dB. The inter-stimuli delay was 30 ms, 60 ms and 120 ms for PPI and 2000 ms and 4000 ms for PPF. Main pulse alone condition was tested as well. Inter-trial interval was chosen randomly between 10 and 20 seconds. In the beginning white noise was played continuously for 3 minutes. The presentation and timing of stimuli was done using E-Prime software. Audio was delivered using audiometric headphones (Etymotic Research, ER-2 tubephone insert headphones 13 mm, Groove Village, USA).

The session lasted for approximately 25 minutes and the main pulse delay was chosen randomly from the set of lengths listed above. The measurement consisted of 69 epochs split into 3 blocks - 5 times main pulse alone, 10 times each main pulse delay length, 4 times main pulse alone. Participants were comfortably sat down facing a white wall to minimize eye movement.

Level of inhibition/facilitation was assessed using startle reflex as a measure. Startle reflex was quantified by measuring EMG of a startle eye blink – activity of musculus orbicularis oculi. Measurement was done following Guidelines for human startle eyeblink electromyographic studies (Blumenthal et al., 2005). Skin was cleaned using ethanol and scratched with a sterile needle. Two pairs of 10 mm AgCl scalp electrodes (EASYCAP, Herrsching, Germany) were used. First one was placed under the bottom eye lids vertically aligned with eye pupils when looking forward. Second one was placed under the outside corners of the eyes. For a schematic of the electrodes placement please see Figure 7. The ground electrode was placed on the forehead. Electrodes were filled with highly conductive gel (Adagel, Neuris, Piešťany, Slovakia). Electrode impendence was kept under 4 kΩ, measured using (SIGGI, EASYCAP, Herrsching, Germany). NeXus-10 (Mind Media B.V., Herten, Germany) and PowerLab (16/35 - PL3516, ADInstruments, Bella Vista, Australia) systems were used with Octal Bio Amp (Octal Bioamp, ML138, ADInstruments, Bella Vista, Australia) amplifier for EMG measurements. Analogue inputs were filtered with analogue filter (1–1000 Hz) and digitalized at sampling rate of 2048 Hz.

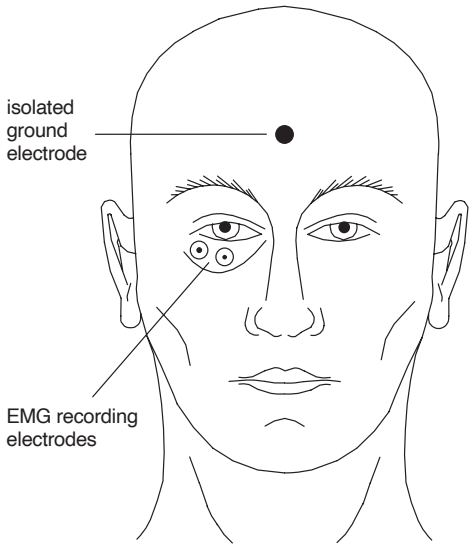

Figure 7: Placement of the left pair and ground electromyography electrodes (Blumenthal et al., 2005)

Additional processing of the EMG data included digital filtering (28–800 Hz bandpass, 48–52 Hz notch), epoching (-100–400 ms compared to onset of the pulse) and discarding epochs containing artefacts (visually checked by humans). Maximum value of rectified wave function of EMG in 21–150 ms interval after the onset of the pulse was considered as the amplitude of the startle reflex. The maximum amplitude in the time interval of 21–120 ms had to be at least two standard deviations higher than in the 0–20 ms interval to pass the threshold of a startle reflex being registered. A single score was calculated for each participant by averaging all measurements for the particular main pulse delay condition and then averaging measurements from both eyes.

2.2.4 Go/no-go task

Cued variant of GNG was used. The action in GNG we have used is a button press. Procedure of one trial of cued GNG was as follows:

- a fixation point (cross) was displayed,
- a blank screen was displayed,
- a cue that was either valid or invalid was displayed,
- a go or a no-go target was displayed last and
- a button press (or lack thereof) from the subject was awaited.

The fixation point was displayed for 800 ms, blank screen was displayed for 500 ms, cue (independently from its validity) was displayed for a random time interval from the following set: 100, 200, 300, 400 or 500 ms and target was displayed until either a response was recorder or for 1000 ms. Intertrial interval was 700 ms. The whole procedure is illustrated by a diagram in Figure 8.

Cues were displayed as white rectangles with black stroke. A horizontal rectangle represented a no-go cue and a vertical one represented a go cue. Cues were valid (i.e., followed by the target they suggested) in 80% of the trials. Targets were displayed as either a blue horizontal rectangle for the no-go target or as a green vertical rectangle for the go target. Spacebar on a keyboard was used as the button to press and participants were instructed to use index finger of their dominant hand to press it. Monitor was placed ~50 cm from the subject and the rectangle sizes were 2.5 cm by 7.5 cm.

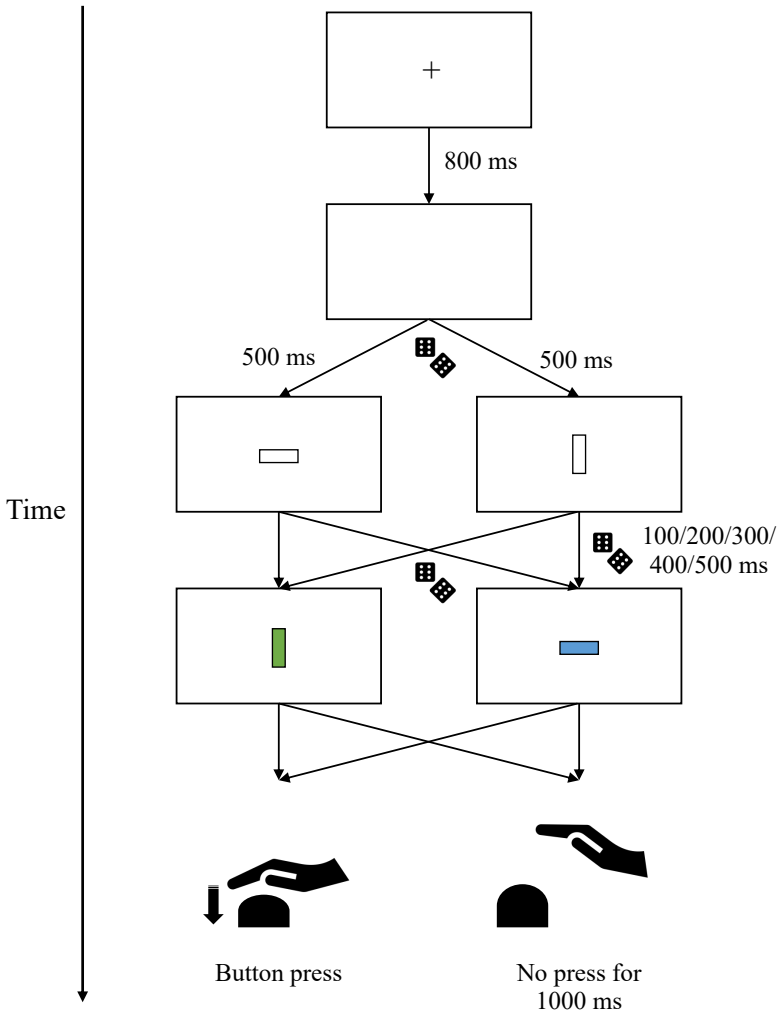

Figure 8: Diagram of one trial of the go/no-go task procedure

250 trials were done by each participant. Number of go and no-go targets was distributed evenly (125 trials for each condition). For each of the conditions the number of valid cues was the same as for the other one (100 trials with valid cue for each condition). For exact split of number of trials by conditions see Table 3. The order of the trials by target and cue validity was random.

Target / Cue	Go	No-go
Go	100	25
No-go	25	100

Table 3: Number of trials for combinations of target condition and cue validity

The go cue no-go target condition causes the participant to prime for the response which then needs to be suddenly inhibited. Out of all four conditions this is the one where failure is most common. It is the critical trial condition for this study since it is best suited to assess subject's ability to inhibit prepotent response (Miller et al., 1991). As can be seen in Table 3 there has been 25 trials under this condition per participant.

2.2.5 Stop signal task

The task we used in SST was to press the button on the side to which the presented arrow was pointing as soon as possible. The participant was instructed not to press a button at all if a stop signal is issued. The whole procedure of one SST trial was as follows:

- white fixation cross was displayed on a black background,
- go signal with an indication which button to press was displayed,
- (stop signal was presented in case of a stop trial,)
- response was awaited.

Fixation cross was displayed for a randomized time from interval of 1 to 5 seconds. Go signal was presented as a white arrow in a circle on a black background pointing to either left or right side, indicating whether "x" or "/" key respectively should be pressed. Stop signal was

auditory. The sound representing stop signal was a 750 Hz sine wave played for 75 ms. It was presented in 25% of trials in random order. The initial SSD (the delay between a go signal and the start of the stop signal) was 250 ms. The delay was adjusted by 50 ms after each stop trial. The adjustment was positive (new SSD = previous SSD + 50 ms) in case of successful previous stop trial and negative (new SSD = previous SSD - 50 ms) in case of failed previous stop trial. This adjusted the difficulty in a closed loop fashion since the later the stop signal is presented the harder it is to inhibit the button pressing action thus the goal is harder to achieve. Response interval was 1000 ms after the last signal (stop signal in a stop trial, go signal otherwise). Intertrial interval was 2000 ms. The diagram of a procedure of one trial can be found in Figure 9.

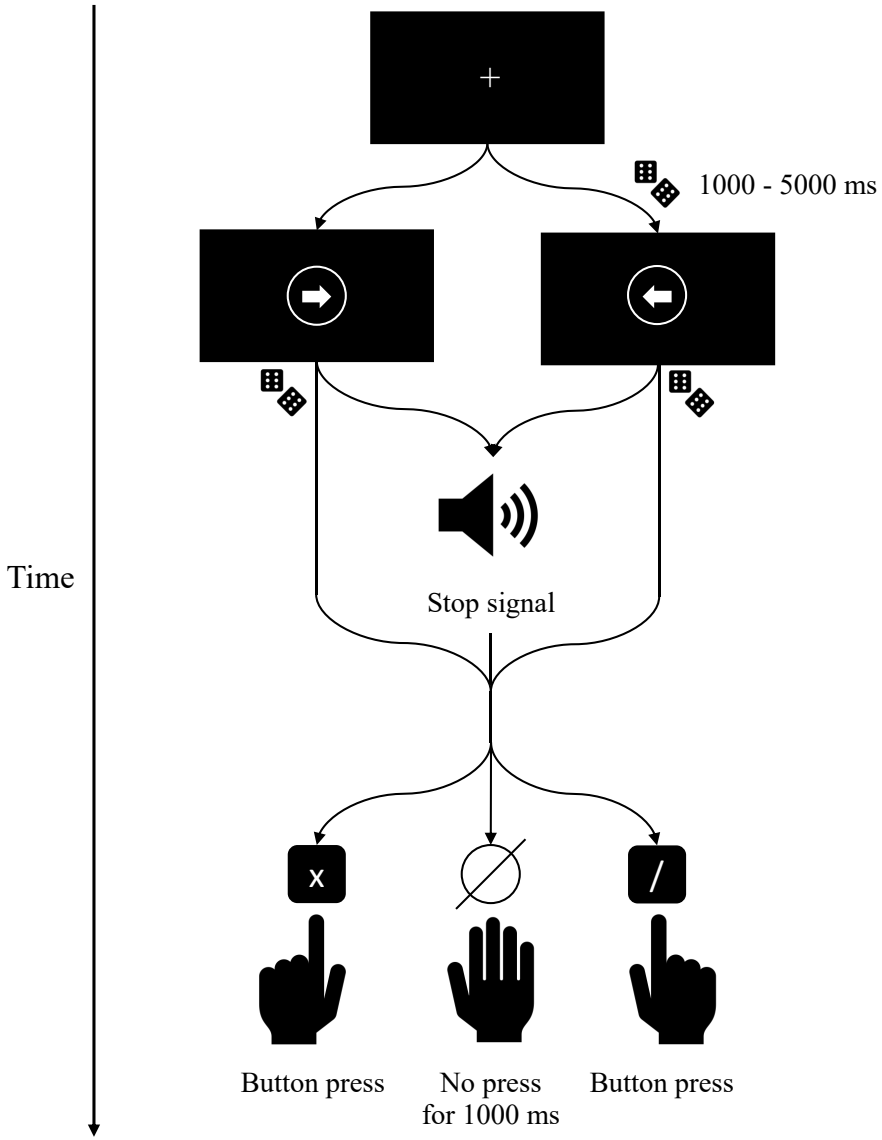

Figure 9: Diagram of one trial of the stop signal task procedure

The task was presented on a monitor ~50 cm away from the participant. The go signal circle diameter was 50 mm and arrow length was 30 mm. The task started with an unrecorded practice session of 32 trials. 3 blocks of 64 trials followed. Length of breaks between trials was regulated by the participant. The whole task session usually took around 10 minutes.

2.2.6 Personality

NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1992) was used to assess five major personality traits of the Big Five model. The inventory consists of 60 items (12 per personality trait) that are individually rated on a five-point Likert scale. Standard procedure was followed.

2.2.7 Schizotypy

Schizotypal Personality Questionnaire (SPQ; Raine, 1991) was used to assess schizotypal traits of the participants. The output of the questionnaire is a score for each of the nine schizotypal personality disorder features as defined by DSM-III-R (Spitzer, 1989). Standard procedure was followed.

2.2.8 Impulsiveness

Personality and behavioral construct of impulsiveness was assessed using a Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995). It is composed of 30 items (not evenly distributed among factors) scored on a four-point scale ("Rarely/Never", "Occasionally", "Often" and "Almost Always"). Output consists of 3 second order factors further split into 2 first order factors per second order factor (total of 6 first order factors, for their list see Table 4). Standard procedure was followed.

2nd order factors	1st order factors
Attentional	Attention
	Cognitive Instability
Motor	Motor
	Perseverance
Nonplanning	Self-Control
	Cognitive Complexity

Table 4: Factors of Barratt Impulsiveness Scale

2.2.9 Statistical analysis

Statistical analysis was conducted using JASP (JASP Team, 2020) statistical software. Dataset was first obtained in **.sav* format (IBM SPSS Statistics, Version 21.0) and was already preprocessed – it was partially labeled and some helping variables were already calculated (e.g., a mean of startle eyeblink amplitudes of left and right eye for PPI measurement). In the analysis we have used the significance level $\alpha = 0.05$ for all statistical tests if not stated otherwise. Particular statistical analysis of each measure is described in detail in chapter 2.3 Results.

2.3 Results

In this chapter we describe the evaluation process and findings for individual measures. In the end we summarize the observed links.

2.3.1 Prepulse inhibition and facilitation

Since PPI and PPF differ only in the delay before the main pulse both were processed and analyzed the same way. We have conducted a factor analysis for PPI measurements (30 ms, 60 ms and 120 ms delays) alone and for PPI measurements combined with PPF measurements (2000 ms and 4000 ms delay). Separate measurements from both eyes were included in both cases. The analysis yielded three factors:

- PPI factor obtained from PPI analysis alone,
- PPI factor obtained from PPI and PPF analysis,
- PPF factor obtained from PPI and PPF analysis.

	RC1	RC2	Uniqueness
ppi30L	0.742		0.402
ppi30R	0.563		0.601
ppi60L	0.888		0.267
ppi60R	0.866		0.278
ppi120L	0.860		0.311
ppi120R	0.784		0.337
ppi2000L		0.794	0.337
ppi2000R		0.725	0.358
ppi4000L		0.869	0.320
ppi4000R		0.834	0.353

Table 5: Component loadings for PPI and PPF factors. The number after ppi represents main pulse delay in milliseconds, the letter after the number represents left and right eye

The division into two separate factors for PPI and PPF shows the distinction between these two phenomena (for more details about the factors see Table 5). There is a very strong correlation between all three PPI conditions (see Table 6); both PPF conditions ($\rho = 0.667$, $p < 0.001$); and a bit weaker but still statistically significant correlation between PPI and PPF factors ($\rho = 0.287$, $p = 0.001$, for more details see Figure 10).

Variable		ppi30	ppi60	ppi120
1. ppi30	Spearman's rho	–		
	p-value	–		
2. ppi60	Spearman's rho	0.556	–	
	p-value	< .001	–	
3. ppi120	Spearman's rho	0.496	0.707	–
	p-value	< .001	< .001	–

Table 6: Correlations between PPI conditions

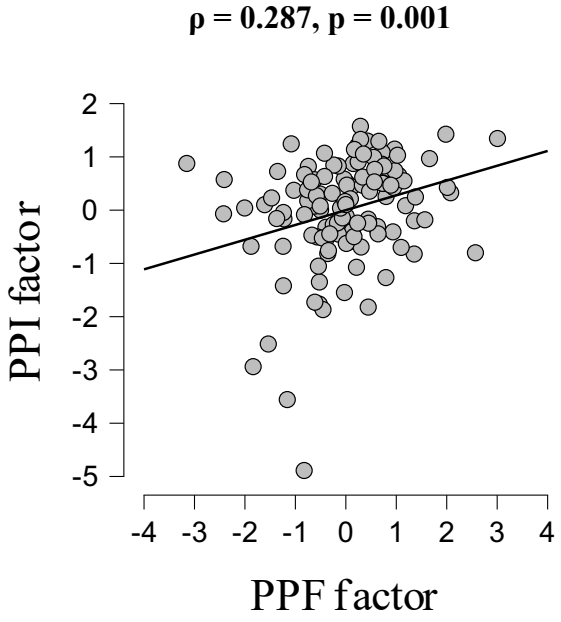

Figure 10: Scatter plot showing correlation between PPI factor and PPF factor

2.3.2 Go/no-go task

A simple descriptive and distribution analysis has shown that our GNG data suffer from floor effect, meaning the task was too easy and all participants got near perfect results with almost no errors made. Maximum error rate was 2.4% (6 errors in 250 trials). Mean error rate was 0.5% (barely above one error in 250 trials). In the critical condition (go cue and no-go target) which also happens to be the most challenging one the maximum error rate was 12% (3 errors in 25 trials) and the mean error rate was 1.3% (0.3 errors in 25 trials). More details can be found in Figure 11.

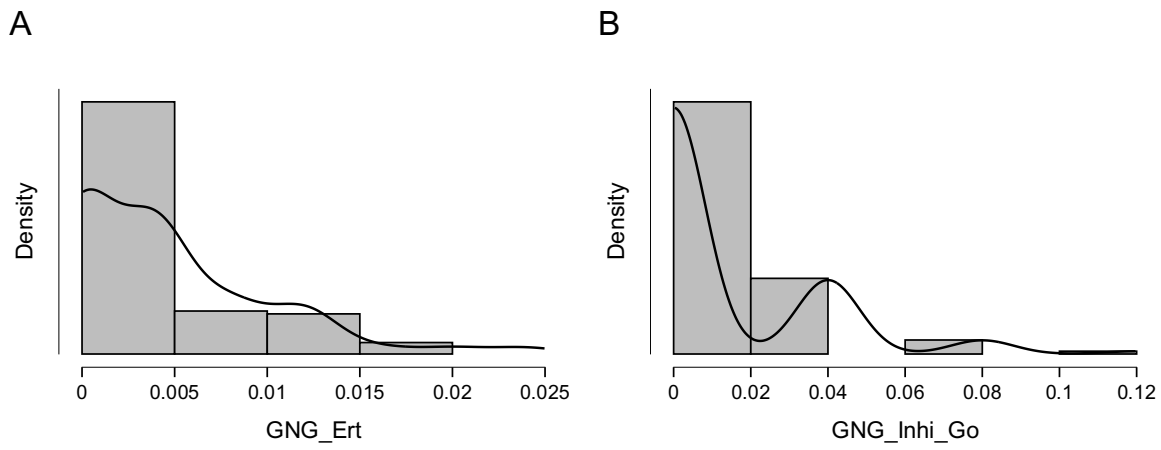

Figure 11: Distribution plots of A: overall error rate in all GNG conditions and B: error rate in the critical condition (go cue and no-go target)

This left us with RTs as usable variables. The RT was normally distributed (see Figure 12) with mean of 329 ms (SD 28 ms). We came up with a manually calculated factor of RT which we call RT delay. RT delay is calculated as a difference between the most difficult measurable trial condition – no-go cue and go target – and the easiest trial condition – go cue and go target. Ideally the critical trial condition – go cue and no-go target – would be used since it requires the highest level of inhibition, however this is not possible since there is no observable action done in corresponding successful trials. The idea behind this factor is that it represents the time participant needed to inhibit the prepotent response and execute the required one. This factor was further used in an analysis in subchapter 2.3.5 Links between measures.

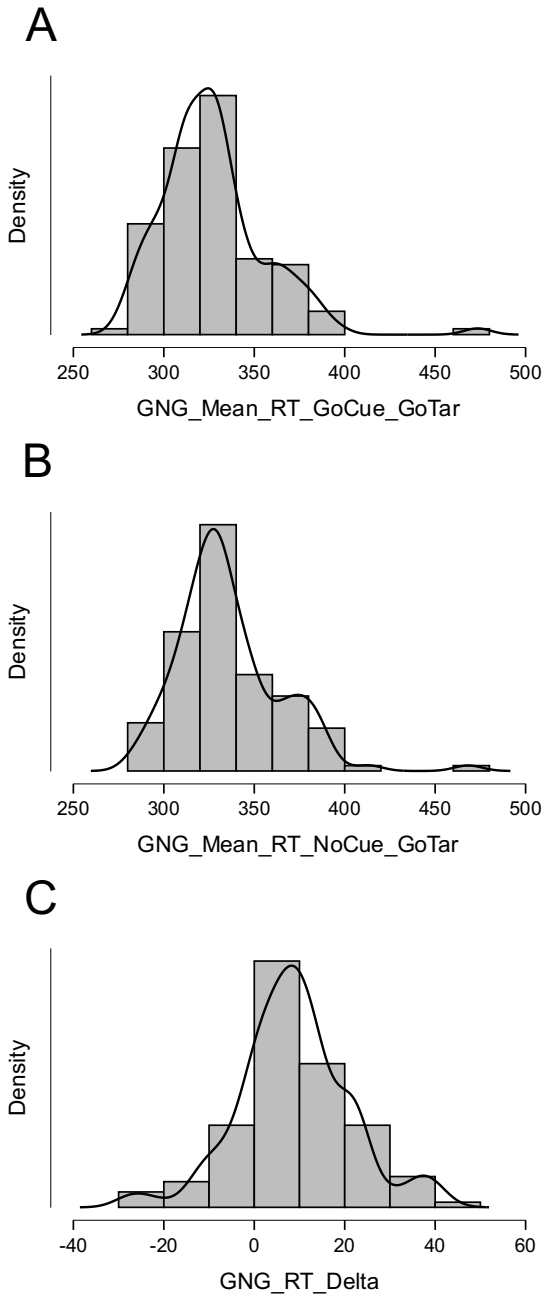

Figure 12: Distribution of A: reaction times of go cue and go target trials, B: reaction times of no-go cue and go target and C: reaction time delay factor

2.3.3 Stop signal task

Since SSD was adjusted in a closed loop it kept oscillating around a value that where inhibition was barely manageable for the participant. This resulted into mean of probability of reaction in stop trial of 48.3% (SD 4.4%). Mean SSD was 357 ms with SD of 185 ms suggesting large differences in performance. Both variables were normally distributed. Conditions for valid SSRT estimation listed in (Verbruggen et al., 2019) were checked and

since they were fulfilled SSRT was calculated using the mean method. More information about these variables can be found in Figure 13.

Two participants were excluded from the analysis of SST because they have not successfully completed any stop trials despite the difficulty adjustment, suggesting that they did not follow the instructions.

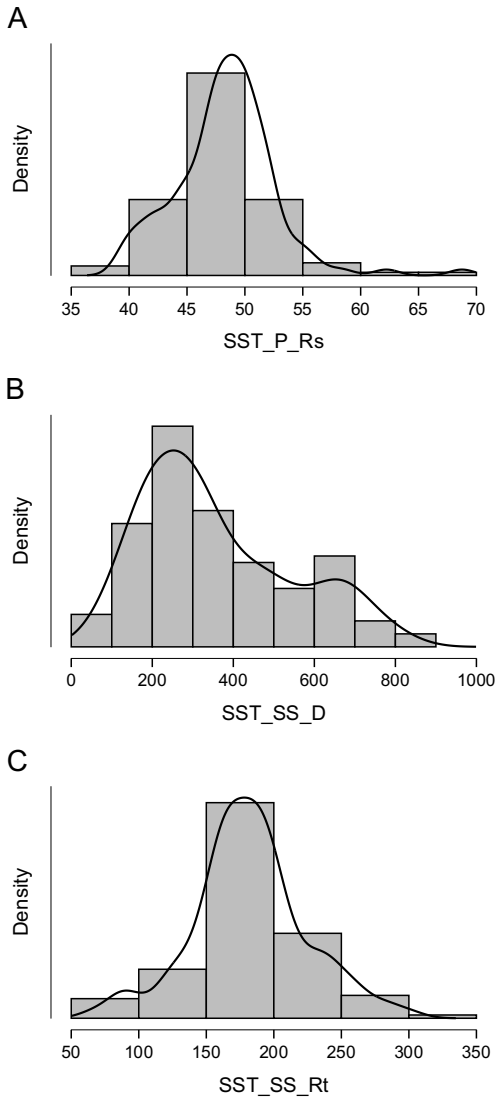

Figure 13: Distribution of A: probability of reaction in stop trial, B: stop signal delay and C: stop signal reaction time

2.3.4 Personality traits

Out of Big Five traits our focus was mainly on Neuroticism since that is the trait most often linked with psychiatric disorders. The neuroticism scores were normally distributed (see panel A of Figure 14). The scores are positively skewed but as discussed in 1.4 Personality

NEO-FFI scores can only be used to compare people within a group and have no meaning on their own so the seemingly low average neuroticism can be deceiving.

Schizotypal scores have non-normal distribution except the total obtained by summing up scores of all of the traits (see panel B of Figure 14). The scores are mostly heavily skewed toward non schizotypal sometimes followed by even distribution which is to be expected because of the recruitment method and criteria.

Second order impulsivity traits captured by Barratt Impulsiveness Scale are evenly distributed. Our focus was mainly on the motor trait since both behavioral measures we are using are motor based. Total impulsivity was calculated by summing up all trait scores. The total score is normally distributed as well (see panel C of Figure 14).

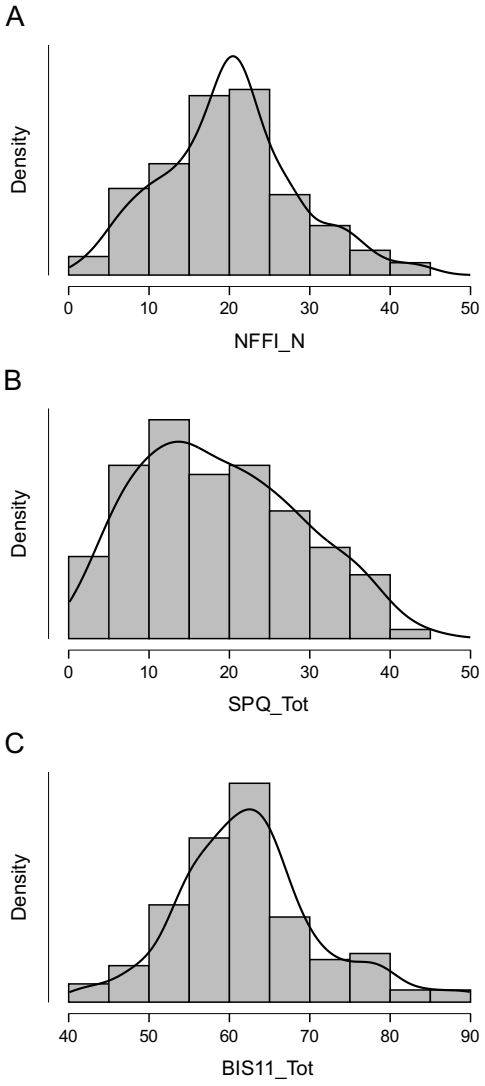

Figure 14: Distribution of A: neuroticism trait obtained via NEO-FFI, B: total schizotypality obtained via SPQ and C: total impulsivity obtained via BIS-11

2.3.5 Links between measures

In this subchapter we present results of an analysis between measures on different levels. The analysis was done with variables as described above. We have also done a 90% winsorization of GNG RT variables, SST SSD and SST SSRT and found it does not affect the outcomes of the results, meaning that no outliers are significantly affecting them.

2.3.5.1 PPI and behavioral measures

Our analysis did not discover any correlations between PPI and neither GNG nor SST. However, we have discovered a novel negative correlation between GNG and PPF. This correlation is between the GNG RT delay and PPF factor ($\rho = -0.225$, $p = 0.012$, for more details see Figure 15). The separate PPF conditions correlate with GNG RT delay as well.

2.3.5.2 GNG and SST

Another negative correlation was found between the GNG RT delay and SST SSD ($\rho = -0.217$, $p = 0.016$) and no other correlations between GNG and SST were found. GNG RT delay is a factor that expresses the extent of how much the invalid cues affect the RTs of a participant. Since it compares times when prepotent response can be utilized and when it needs to be inhibited and replaced by a different one, we consider it to be an indicator of the inhibition ability. More details about the GNG RT delay factor are available in subchapter 2.3.2 Go/no-go task. SSD is a mean of delays between a go signal and a stop signal in all trials of a particular participant. The difficulty of the task is heavily impacted by this variable since larger delay means action execution is closer to finished at the time of the stop signal and there is less time for inhibition to succeed. Unlike SSRT it does not compensate for the RT which makes it harder to draw conclusions based on this variable.

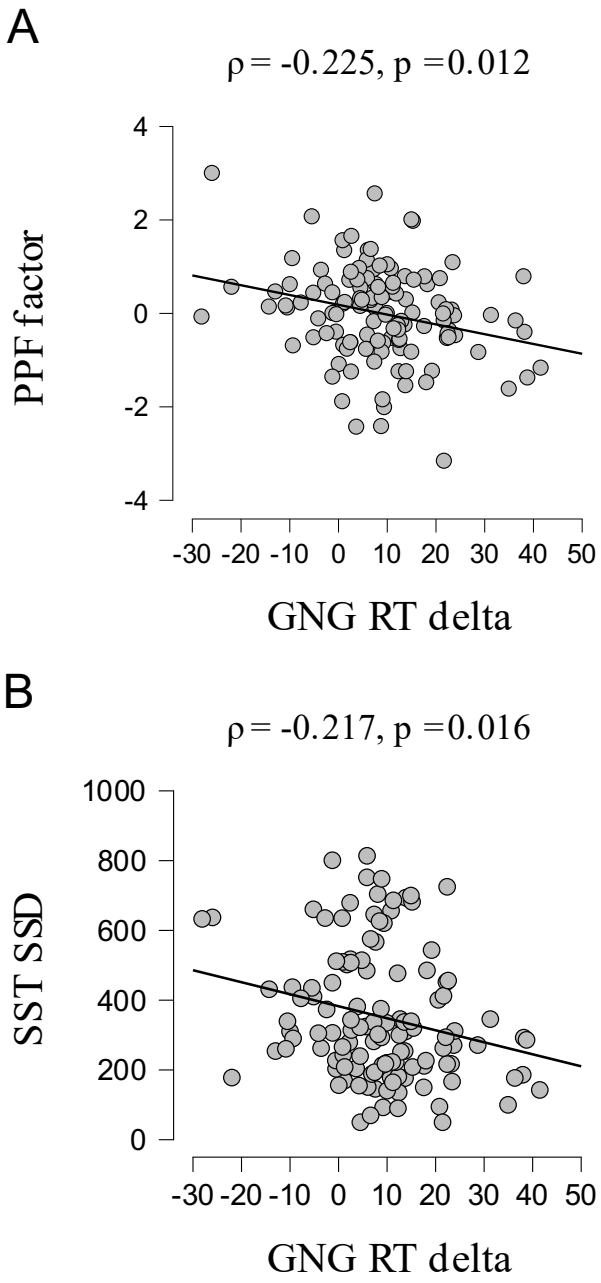

Figure 15: Scatter plots showing correlation between A: the GNG RT delta and B: PPF factor and SST SSD

2.3.5.3 Traits and lower-level measures

None of the traits correlated with PPI nor PPF. Out of behavioral measures we have found a negative correlation between schizotypal trait of eccentric/odd behavior and error rate of the critical condition of GNG – go cue and no-go target ($\rho = -0.178$, $p = 0.049$). However, with floor effect in GNG and p value just below the threshold this has to be interpreted with caution. Another negative correlation was found between schizotypal trait of odd beliefs and

error rate in SST ($\rho = -0.210$, $p = 0.020$). Multiple correlations between different traits were found. In particular between neuroticism and schizotypality (see Table 7), neuroticism and attentional trait of impulsivity ($\rho = 0.183$, $p = 0.043$) and impulsivity and schizotypality (total with total $\rho = 0.232$, $p = 0.010$; for particular traits see Table 7). The evaluation of correlations between traits was done as a part of exploratory analysis. Due to multiple comparisons performed in this analysis we applied Bonferroni multiple result-comparison correction and as a result significance level changed to $\alpha = 0.003$.

1st variable	2nd variable	Spearman's ρ	p value
NEO-FFI Neuroticism	*SPQ Total*	*0.401*	*<0.001*
NEO-FFI Neuroticism	*SPQ Ideas of reference*	*0.281*	*0.002*
NEO-FFI Neuroticism	*SPQ Social anxiety*	*0.572*	*<0.001*
NEO-FFI Neuroticism	SPQ No close friends	0.225	0.013
NEO-FFI Neuroticism	SPQ Odd speech	0.182	0.044
NEO-FFI Neuroticism	SPQ Constricted affect	0.220	0.014
NEO-FFI Neuroticism	*SPQ Suspiciousness*	*0.396*	*<0.001*
SPQ Total	BIS Attentional	0.195	0.030
SPQ Total	BIS Nonplanning	0.202	0.025

Table 7: Details of correlations between traits

2.4 Discussion

Surprisingly we did not find any links between PPI and schizophrenia related personality traits. We did find a link between GNG and SST. Some correlations between the behavioral measures and traits were discovered as well, however they are between very specific variables and traits and the p values are not particularly convincing. No correlation between PPI and any of the behavioral measures was found. However, we did find a correlation between GNG and PPF, which is a related phenomenon.

We expected to find a link between PPI and schizophrenia related personality traits since PPI deficit is a well-documented finding in schizophrenia. However, we did not find one. One of the explanations of this might be the fact that our sample did not score very high in these traits. This is because recruitment not only did not specifically target people with schizophrenia (estimated prevalence of which is between 0.5% and 1% so there would be a rather large chance of our sample simply not including enough participants with schizotypal trait scores high enough to uncover links like this) but we specifically excluded people with diagnosed psychiatric disorders (McCutcheon et al., 2020; McGrath et al., 2008).

In the analysis of links between GNG and SST we found a correlation between RT delay, which we consider to be one of the GNG factors, and SSD which is an important variable in SST. SSD itself correlates with SSRT; however, our analysis did not discover a correlation between GNG RT delay and SST SSRT. Therefore, from the standpoint of overall interchangeability of GNG and SST, while our findings suggest that there are some links between those two measures, they also suggest that GNG and SST measure slightly different processes. This is more or less in line with findings of others, which discovered that the measures usually correlate but under specific conditions, mainly concerning the demographic, they do not. This was a reason for uncertainty from the beginning of the hypothesis creation process. On one hand the measures were for a long time considered as interchangeable, which was of course supported by corresponding findings. Therefore, we expected to find a correlation since our conditions should qualify as standard. On the other hand, based on the more recent finding we know that GNG and SST are not actually interchangeable so we knew that the actual findings might differ from these expectations because of unpredicted factors.

We did not expect to find any major correlations between the behavioral tasks and the traits since multiple studies concluded that there are no such correlations (Bari & Robbins, 2013;

Broos et al., 2012). However, we used multiple questionnaires measuring many traits, so it is not a surprise that some particular traits correlate with PPI. In particular it is two seemingly random traits (schizotypal trait of eccentric/odd behavior and schizotypal trait of odd beliefs) correlating with specific variables (GNG go cue no-go target error rate and SST error rate respectively) of the behavioral measures. No explanation why these particular variables correlate comes to our minds and to the best of our knowledge there are no publications explaining this matter are available. Because of relatively high p-values which are above threshold of statistical significance after Bonferroni multiple result-comparison correction we assume this was a fluke.

When hypothesizing we knew that the current state of research suggests that GNG and SST measure related but different processes. The link between PPI and either of those measures was unknown. We decided to hypothesize that they are not linked based on the fact that the current state of the research was that in cases that were studied behavioral measures did not correlate with trait measures. This hypothesis was mostly confirmed by our study. However, we have found a correlation between PPF and GNG. Since this correlation is between the PPF factor (and stays consistent with both PPF conditions separately as well) and is with one of the two critical GNG variables (and the only one available to us since we have struggled with floor effect in error rates as described previously) we believe these warrants further research. A hypothesis linking prepulse in PPF with cue in GNG comes to mind, which could explain this finding. A separate study focusing specifically on PPF and GNG could help uncover whether this was just a coincidence or a mistake because of incorrect experiment design or a meaningful link shedding more light on inhibition.

2.4.1 Limitations

We see multiple improvements that could be done to the experiment design to increase the validity of the results and potentially uncover novel findings.

First, the design of GNG we have used apparently makes completing the task perfectly too easy, a result of which is the floor effect we have struggled with. This appears to be a common issue with for example Verbruggen & Logan (2008a) reporting 96% critical condition success rate in their GNG study. This leads to losing one of the two variables measured in GNG which might hide some important links. Possible ways of increasing the difficulty are by increasing the cue validity (in the current setup it was 80%) which would however require even more trials to gather enough data for the critical condition, decreasing

the interval for which the cue is displayed (in the current setup it was displayed for up to 500 ms), and progressively changing the representations of go and no-go signals as suggested by Verbruggen & Logan (2008a) and discussed in subchapter 1.3.1 Go/no-go task.

In SST all of the major guidelines for SST studies proposed by Verbruggen et al. (2019) were followed. One small detail that could be improved is using variable intertrial interval (in our case fixed intertrial interval of 2000 ms was used) which helps fight various strategies using anticipatory responses. This detail was missed because the actual experiment design and data acquisition were done before the guide was published and therefore the check of the guidelines happened in retrospect.

Another variation that could be done in a future study is including two groups of participants, one of which would be schizophrenics or people with extraordinarily high schizotypality. This could specifically help shed more light on links between traits (especially schizotypality) and measures on other levels. If we further generalize this idea there might be some links that only appear if participants with a particular and diagnosed psychiatric condition are included. This would of course require specific analysis.

On meta level, the measures used in this thesis are currently the best tools we have for scientific studies and evaluation of inhibition. They offer quick, precise and easily quantifiable way of observing inhibition on different levels. However, it is questionable how much they reflect the complex reality of the real life. In real life action restraint and action cancelation rarely happen with stimuli as pure and clear as the ones used in GNG and SST and the "trials" do not tend to occur over and over again with a person fully focusing in advance on their successful completion. Computers and computer science are great tools for cognitive science research, but we should keep these generalization limitations in mind. The same limitation applies to self-report questionnaires. Their validity has been discussed times and times again and while they are still the best tool we currently have they will always have the inherent issue of being subjective which can affect the results, especially if they could make the participant uncomfortable – a phenomenon known as social desirability bias (Demetriou et al., 2015).

Conclusion

The aim of this thesis was to critically evaluate the links between three different levels of inhibition. These links previously were not complexly studied and were only partially understood. As intended our study helped shine more light on the concept of inhibition. In science breakthrough studies sometimes happen but more often than not the scientific knowledge is slowly advanced bit by bit. The former is also the case of this thesis which includes multiple new discoveries and shows the way of what should be studied further.

As for the particular findings. Our study has not discovered any links between prepulse inhibition and behavioral nor traits level. A finding that is novel and can be shocking. Yet another interesting discovery we have achieved is that we found a previously unknown link between PPF and a behavioral measure go/no-go task which could serve as a starting point for future studies, potentially linking the various levels in the end. We confirmed that although go/no-go task and stop signal task are related, they are not interchangeable in all cases. It was previously observed that behavioral measures of inhibition and trait measures are usually independent of each other. This was also our finding. However, we found multiple strong links across different trait measures related to inhibition deficiency. This is in line with the observation that the strongest links are within the levels, not across them.

These findings suggest that while there are some observable links between the different levels which we have studied, interestingly all levels appear to utilize mostly independent cognitive processes. This observation could lead to a creation of a new paradigm in the domain of inhibition. As was demonstrated in the theoretical part of the thesis, the concept of inhibition is not only important for cognitive science and research, but it is also heavily utilized in clinical psychiatry. Therefore, any advancement in this field can have potentially life changing implications for people suffering with various psychiatric conditions which can in turn impact the whole society in various positive ways.

To recapitulate the process that led to the completion of this thesis. First, we reviewed the current state of the art of inhibition research. We started with brief history and continued with the current state. In the review, studies from multiple scientific disciplines were included. In particular philosophy, neuroscience and psychology. The latter two of which were of our main interest since they are the disciplines we have decided to utilize in the empirical part. In the review we mostly focused on three levels on which inhibition can be observed. These levels are physiological, behavioral and level of personality traits. We used

the information acquired by doing the review to describe the experiment design (since it was inherited from a larger project), verify its validity, analyze the results and discuss the whole study.

On physiological level we used prepulse inhibition as a measure of inhibition. Prepulse inhibition is a phenomenon in which the startle response is decreased if a startle stimulus is shortly preceded by a weaker prepulse. If the delay between the stimuli is long enough, the opposite happens and response is increased, which is a phenomenon known as prepulse facilitation. Prepulse inhibition was measured using a standardized procedure and all typical conditions were tested (main pulse delay of 30 ms, 60 ms and 120 ms for prepulse inhibition and main pulse delay of 2000 ms and 4000 ms for prepulse facilitation).

On behavioral level we decided to focus on action restraint and action cancelation. We used the most commonly used measures which are go/no-go task for action restraint and stop signal task for action cancelation. A cued variant of go/no-go task was used in which the participant is instructed to press a button or avoid pressing it depending on a presented target which is preceded by a cue with validity lower than 100%.

In stop signal task participants are instructed to do an action to complete a simple task but avoid it if stop signal is presented. Stop signal is always presented with a delay after the go signal. Stop signal task procedure was done in line with guidelines proposed by Verbruggen et al. (2019).

Out of personality traits we focused on neuroticism trait of Big Five model, schizotypal traits as defined by Diagnostic and Statistical Manual of Mental Disorders and personality trait of impulsivity. All of these traits were measured using self-report questionnaires. In particular NEO Five-Factor Inventory was used to quantify Big Five traits, Schizotypal Personality Questionnaire was used to quantify schizotypal traits and Barratt Impulsiveness Scale was used to quantify impulsivity.

The goal of this thesis was successfully achieved by utilizing different measures of inhibition on a group of a participants and analyzing the results. Along the way we discovered multiple novel findings which can provide a base for further scientific work to complexly understand inhibition. Therefore, we consider this project a success.

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