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Links between self-reported and laboratory behavioral impulsivity

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A major problem in the research considering impulsivity is the lack of mutual understanding on how to measure and define impulsivity. Our study examined the relationship between self-reported impulsivity, behavioral excitatory and inhibitory processes and time perception. Impulsivity – fast, premature, thoughtless or disinhibited behavior – was assessed in 58 normal, healthy participants (30 men, mean age 21.9 years). Self-reported impulsivity as measured by Adaptive and Maladaptive Impulsivity Scale (AMIS) and behavioral excitatory and inhibitory processes as measured by Stop Signal Task were not directly related. Time perception, measured by the retrospective Time Estimation Task, was related to both. The length of the perceived time interval was positively correlated to AMIS Disinhibition subscale and negatively to several Stop Signal Task parameters. The longer subjects perceived the duration to last, the higher was their score on Disinhibition scale and the faster were their reactive responses in the Stop Signal Task. In summary our findings support the idea of cognitive tempo as a possible mechanism underlying impulsive behavior.

Key words: Impulsivity, self-reported impulsivity, time estimation, time perception, Stop Signal Task, response inhibition.

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INTRODUCTION

Impulsivity – fast, premature, thoughtless and disinhibited behavior – has been consistently related to several problematic behaviors such as risky driving (Paaver, Eensoo, Pulver & Harro, 2006), aggression (Vigil-Colet & Codorniu-Raga, 2004), drug abuse (Colder & Chassin, 1997), and gambling (Blaszczynski, Steel & McConaghy, 1997), as well as to a variety of psychopathological disorders (e.g. ADHD, personality disorders). In general, impulsivity can be considered as disposition not to deliberate much before reacting to external or internal stimuli. One main problem in the research of impulsivity is the lack of agreement on how to define and measure impulsivity (Evenden, 1999). Dickman (1990), representing self-report measures, defines impulsivity as a tendency to deliberate less than most people of equal ability before taking action, while Schachar and Logan (1990), representing laboratory behavioral measures, see impulsivity as revealing deficient inhibitory control. Evenden (1999) has successfully summarized various definitions by stating that impulsivity consists of a wide range of actions that are ‘‘poorly conceived, prematurely expressed, unduly risky or inappropriate to the situation and often result in undesirable outcomes’’ (p. 348). As such, it plays a role in normal as well as in pathological behavior.

Most of the widely used research methods in studying impulsivity can be divided in two categories: (a) self-report measures or questionnaires and (b) laboratory behavioral measures, for example tasks measuring response inhibition, delay of reinforcement and behavioral timing (Dougherty, Mathias, Marsh & Jagar, 2005; Evenden, 1999). Two different laboratory behavioral measures – Stop Signal Task (SST) and retrospective verbal Time Estimation Task (TET) – along with a self-report measure, Adaptive and Maladaptive Impulsivity Scale (AMIS), were used in the current study. We hope to provide support to previous proposals (Wittmann & Paulus, 2008) that cognitive tempo might be a suitable candidate for an underlying mechanism mediating impulsive behavior.

Self-reported impulsivity

Trait impulsivity has most often been assessed by various self-report questionnaires like the Barratt Impulsiveness Scale (BIS-11) (Patton, Stanford & Barratt, 1995), Dickman Impulsivity Inventory (DII) (Dickman, 1990), I_7 Impulsiveness questionnaire (Eysenck, Pearson, Easting & Allsopp, 1985), Temperament and Character Inventory (Cloninger, Przybeck & Švarkić, 1991) or Sensation Seeking Scale (Zuckerman, 1994). The main problem with abovementioned (and other) questionnaires is that they all measure slightly different facets of impulsivity. The facets tend to be correlated but not completely overlapping (Reynolds, Ortengren, Richards & de Wit, 2006). To have a better theoretical understanding of what unites these measures, one possibility is to anchor different aspects of impulsivity to already validated higher-order personality structures. Several well-known impulsivity questionnaires together with the NEO-PI-R personality questionnaire (Costa & McCrae, 1989, 1992) were factor-analyzed in a study by Whiteside and Lynam (2001). Four subscales of the NEO-PI-R were independently related to the extracted impulsivity factors: Deliberation loaded to Premeditation, Impulsiveness to Urgency, Excitement Seeking to Sensation Seeking, and Self-Discipline to Perseverance. Thus the study of self-report impulsivity

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already indicates that impulsivity, although complex, is well embedded into currently used personality measures.

The traditional negative view of impulsivity was directly challenged by Dickman (1990), who argued that in addition to negative or dysfunctional consequences, impulsivity may also lead to positive or functional outcomes. Smillie and Jackson (2006) proposed an idea that Dickman's Functional Impulsivity (FI) bears conceptual similarity to Gray's Reinforcement Sensitivity Theory's (RST) concept of reward reactivity. Reward reactivity is presumably caused by the combined effects of Behavioral Activation System (BAS) and Behavior Inhibition System (BIS). Based on their two studies, they concluded that FI, along with measures of BAS, predicted the development of a response bias for the rewarded alternative. Dysfunctional impulsivity (DI) – acting with little or no forethought when this is not optimal and leads to difficulty – on the other hand, was found to be largely unrelated to FI and RST. While FI may have an underlying basis in the motivational systems of RST, it remains unclear how FI and DI are linked and whether they share similar underlying bases (Smillie & Jackson, 2006). Some researchers (Franken & Muris, 2006; Smillie & Jackson, 2006) have even suggested that FI, or in other words reward sensitivity, and DI that is traditionally considered as impulsivity are actually two different traits.

Laboratory behavioral measures of impulsivity

The same problem considering self-report measures applies to laboratory-based behavioral measures of impulsivity. Paradigms such as the Two Choice Impulsivity (a delay discounting task where the participant has to choose between larger rewards after longer delays or smaller rewards after shorter delays), the Single Key Impulsivity (measuring the rate and pattern of free operant responses for reward, reward is dependent on the delay between two consecutive responses), the Stop Signal (assessing the capacity to inhibit an already initiated response) and the Time Perception (producing or assessing time periods) also look at slightly different aspects of impulsivity (Dougherty *et al*., 2005; Reynolds *et al.*, 2006). Reynolds *et al*. (2006) found only one significant but weak correlation between popular laboratory behavioral measures of impulsivity. Participants with longer stop reaction times in the SST made more false-alarm errors on the Go/No-Go Task (measuring ability to choose between response execution and inhibition by pressing a button in response to one type of stimulus and withholding a response to another). In a principal component analysis of all paradigms, they extracted two components of impulsivity: ''impulsive disinhibition'' consisting of performance in SST and Go/No-Go task (i.e., inability to refrain from response), and ''impulsive decision-making'' related to performance in Delay Discounting (measuring the tendency to prefer immediate rewards over delayed ones) and Balloon Analogue Risk Task (measuring behavioral risk taking: participant has to inflate a balloon and every pump is rewarded up until an explosion point at which the reward collected in the trial is lost). It should be noted that according to contemporary understanding the SST and Go/No-Go Task are not equivalent and allow different response inhibition (Swick, Ashley & Turken, 2011; Verbruggen & Logan, 2008a).

Behavioral excitatory and inhibitory processes

Behavioral excitatory and inhibitory processes, typically modeled by the SST, are described by the Horse-Race Model (Logan & Cowan, 1984). The model assumes that initiation and cancellation of reaction are two largely independent processes – the ability to give a quick reactive response and the ability to inhibit a response (stopping process). If the stopping process wins, response is inhibited, and if the ongoing process wins, response runs to completion. The performance in the SST reflects both processes. The inability to stop (as one of the main indicators of impulsivity) is caused either by the short reaction time (Butler & Montgomery, 2005), the slow response inhibition, or a failure to respond to the stop signal occurrence (Logan, Schachar & Tannock, 1997; Schachar & Logan, 1990).

Previous studies have found that after-effects of the preceding trial may influence performance in the following trial (Rieger & Gauggel, 1999). Trial order effect can either result in a switch cost or repetition benefit (Monsell, 2003). In the context of SST, Rieger & Gauggel (1999) demonstrated that RTs on Go trials following Stop trials, irrespective whether their inhibition was successful or not, become longer. On the contrary, the findings by Verbruggen, Liefooghe & Vandierendonck (2005) showed no slowing of the RTs following trials requiring response inhibition. The after-effects of successful and unsuccessful stopping have been previously used to study children with Attention Deficit Hyperactivity Disorder (ADHD, a disorder characterized by impulsive behavior). Children with ADHD diagnosis proved to slow their responses less than controls following unsuccessful stopping (Schachar, Chen, Logan, Ornstein, Crosbie, Ickowicz & Pakulak, 2004). So far the after-effects have not been considered in the research concerning the relationship between different impulsivity measures. This could be one additional resource to help explicate the situation.

Successful performance in the SST also involves go and stop preformance monitoring and response strategy adjustment. The optimal balance between conflicting demands of responding as quickly as possible and stopping the response must be found. It has been suggested that subjects change response strategies proactively when they expect stop signals to occur or reactively after the Stop trials (Verbruggen & Logan, 2008b).

Another adjustment influencing performance is called temporal preparation. Temporal preparation is caused by regular changes in the environment that lead to anticipation and preparation of efficient behavior to forthcoming events. The optimal state of preparation flexibly adjusts to the moment at which a task-relevant event is expected to occur and it can be controlled voluntarily (Correa, Triviño, Pérez-Dueñas, Acosta & Lupiáñez, 2010). Correa *et al*. (2010) found that impulsivity could be related to less efficient temporal preparation of inhibitory processing.

Time perception

The use of different impulsivity measures and theories within distinct research domains implies the lack of unitary conceptualization (Evenden, 1999; Moeller, Barratt, Dougherty, Schmitz & Swann, 2001). All the more, the research area of impulsivity would benefit from attempts to reach a common ground between

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diverse theoretical understandings. One relatively basic concept to unite the ''varieties of impulsivity'' could be the time perception (Evenden, 1999). Research has found negative correlations between time perception accuracy and laboratory-based behavioral as well as self-reported impulsivity measures (Barratt, 1993; Dougherty, Bjork, Harper, Mathias, Moeller & Marsh, 2003). For instance, Wittmann, Leland, Churan and Paulus (2007) showed that high scores on the non-planning facet of the BIS-11 explained the difference between substance dependence and a control group in a 53-second Time Estimation Task. Correa *et al.* (2010) compared healthy individuals with high and low levels of impulsivity and found that subjects with high impulsivity levels produced larger time overestimations than the low impulsivity group. However, time perception does not relate to all measures of impulsivity (Gorlyn, Keilp, Tryon & Mann, 2005), which gives reason for specifying the pattern of interrelations in a more detailed way.

Why should subjective time flow be related to impulsiveness at all? The model of time perception by Wittmann & Paulus (2008) is based on accumulation of pulses coming from an internal clock (see Fig. 2 in Wittmann & Paulus, 2008). The rate of the accumulation of pulses determines the perceived length of an interval. Previous studies have found that impulsive individuals have an altered sense of time – their subjectively perceived accumulation of pulses is speculated to be faster, resulting in overestimation of interval duration (see Wittmann & Paulus, 2008 for prevalently clinical data). This phenomenon could explain the well-known tendency of more impulsive persons to show greater preference for immediate but smaller rather than delayed but larger rewards, and also their proneness to respond without premeditation. These typical behaviors represent two models of impulsivity: the reward-discounting and the rapid-response model, respectively (Swann, Bjork, Moeller & Dougherty, 2002).

Neurobiological correlates of impulsivity

The multifaceted nature of both self-report and laboratory behavioral measures, as well as controversial results of studies on the relationships between and within both approaches (Enticott, Ogloff & Bradshaw, 2006; Reynolds *et al*., 2006) might be explained by the multitude of neurobiological correlates found to take part in forming impulsive behavior. It has been discovered that monoaminergic neurotransmitter systems and cortico-striatal pathways are related to impulse control, whereas nucleus accumbens, amygdala and cerebellum deal with reward, decision making and reinforcement (King, Tenney, Rossi, Colamussi & Burdick, 2003). Aron and Poldrack (2006) described that reacting to Go stimuli in SST activated frontal, striatal, pallidal, and motor cortical regions, whereas reacting to Stop signals activated right inferior frontal cortex and subthalamic nucleus. Pharmacological studies with animals show that different tasks assessing impulsivity in the preparation, execution and outcome of actions, are modified independently by different drugs (reviewed by Evenden, 1999).

The special role of time perception in impulsivity is also supported by several lines of neuropsychological research. Regions in the right prefrontal cortex have been found to be involved in time perception, delay discounting (Wittmann & Paulus, 2008) and response inhibition (Horn, Dolan, Elliott, Deakin & Woodruff, 2003). Berlin, Rolls and Kischka (2004) found that lesions in orbitofrontal cortex resulting in altered time perception were related to higher impulsiveness measured by BIS-11.

Current study

The aim of the current study is to contribute to a better understanding of the relationship between different approaches – self-report and laboratory behavioral – employed to measure impulsivity. SST and retrospective verbal TET included in the study represent laboratory behavioral measures, self-reported impulsivity is assessed by AMIS. Based on previous findings, we assume to find no direct evidence of self-reported impulsivity and SST to be strongly related. The results of TET are predicted to be related to both aforementioned measures, hence providing proof for the suggestion that cognitive tempo might be one of the mechanisms underlying impulsive behavior. We take a closer look at the trial after-effects by analyzing data of the SST in a more detailed way. As the after-effects have not been studied in the context of investigating the relations between different impulsivity measures, we aim to examine their relationship to self-reported impulsivity and TET and to provide a new understanding on a more detailed level.

METHOD

Participants

Healthy volunteers, currently undergraduate, graduate or open university students, participated in the study (30 males, 28 females, mean age 21.9 years, $SD = 2.7$ years).

Procedure

All participants signed informed consent to the procedure and the Declaration of Helsinki guidelines were followed in the study. Optional feedback was provided on request and psychology students had a possibility to receive course credits. Every subject was tested individually. Data was collected in two sessions. First session consisted of 43 participants (mean age 21.5, $SD = 2.8$ years, 15 male, 28 female). The test-session for each subject lasted 1.5–2 hours and the testing was conducted in the following order: pre-test, main test and post-test session. Pre- and post-test sessions consisted of the following tasks (presented in order of administration): Borg Category Ratio Scale (Borg, 1998), Critical Flicker Frequency (Simonson & Brozek, 1952), Digit Span, Backward Span, 2-Back Task, a version of the Visual Pattern Test (Della Sala, Gray, Baddeley & Wilson, 1997). Tasks in main session were as follows: a version of Corsi Test, Santa Barbara Sense-of-Direction Scale (Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002), Map Learning Task's first part (e.g. Bosco, Longoni & Vecci, 2004), SST and Map Learning Task's second part. After the post-test session subjects completed impulsivity questionnaires AMIS and DII (Dickman, 1990). In order to balance the gender composition of the sample, the data from an additional 15 male participants (mean age 22.9, $SD = 2.3$) from a pre-test of another study on heat acclimation and exercise were included. After some physiological measurements the cognitive pre-test consisted of following tasks: Borg Category Ratio Scale (Borg, 1998), Simple Reaction Time Task, Two Back Task, a version of the Visual Pattern Test (Della Sala *et al*., 1997) and SST. The impulsivity questionnaire was administered online after the testing. The two samples received treatment lasting about the same time before SST in both sessions under investigation.

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Self-reported impulsivity measures

Participants were asked to fill the AMIS – a 24-item scale which is compiled using items from Functional and Dysfunctional Impulsivity scales (Dickman, 1990) and two impulsivity-related scales from the five factor model of personality (Costa & McCrae, 1992) – Impulsivity and Excitement Seeking of the Estonian version of the International Personality Item Pool (Mõttus, Pullmann & Allik, 2006, originally Goldberg, 1999). AMIS consists of four subscales: Disinhibition (Impulsiveness, Cronbach alpha = 0.70, AMIS-I), Excitement Seeking (Cronbach alpha = 0.80, AMIS-E), Fast Decision-Making (Functional Impulsiveness, Cronbach alpha = 0.71, AMIS-F) and Thoughtlessness (Dysfunctional Impulsivity, Cronbach alpha = 0.78, AMIS-D). AMIS-E and AMIS-F together form Adaptive Impulsivity, AMIS-I and AMIS-D represent Maladaptive Impulsivity factors. The scale has been used repeatedly under parallel names for the subscales given above (e.g., by Eensoo, Harro, Pullmann, Allik & Harro, 2007; Eensoo, Paaver, Pulver, Harro & Harro, 2004; Paaver *et al*., 2006; Paaver, Kurrikoff, Nordquist, Oreland & Harro, 2008).

Laboratory behavioral measures of impulsivity

Behavioral excitatory and inhibitory processes. A Dell Latitude D830 computer and a free-ware program PEBL 0.08 was used for SST. The SST (50 Stop and 150 Go trials after 20 practice trials with feedback) was used to assess behavioral excitation and inhibition. In Go trials, the task instruction was to react as fast as possible to the occurrence of a full blue circle (diameter of 4 cm) on the computer screen (at the viewing distance of 70 cm) by pressing the space button during a timeframe of 1 s. In Stop trials, the blue circle was followed by a red cross (the length of one full line of the cross was 11 cm). The red cross appeared on the ring with a variable delay, and it was forbidden for the participant to press the button (see Fig. 1). The first delay was always 150 ms. Successful response inhibition lengthened and premature response shortened the delay by 10 ms. The next trial appeared with a jitter time (a blank screen) ranging from 500 to 2500 ms from the disappearance of the previous stimulus. If the reaction was not inhibited, reaction time (RT) was registered in the same way as in Go trials, but the stimulus stayed on the screen for the full 1 s. The stimuli appeared blockwise in a random order, Stop trials never occurred more than twice and Go trials more than six times in a row. The instruction emphasized both speed and accuracy.

For each subject, median RT for correct Go trials (GoRT) was computed. Stop signal delay (SSD) was calculated as the average of the final three stop signal delays. Stop signal reaction time (SSRT) was estimated by subtracting SSD from the median GoRT. These parameters are typically used in studies employing SST (e.g., Aron & Poldrack, 2006; Band, van der Molen & Logan, 2003). Additional information on discrimination was obtained from the proportion of correct responses in Go trials (GoOK) and the proportion of correct inhibitions in Stop trials (StOK). RT was registered for commission errors (StRT) – when response was not inhibited. Repeated and switch trial RTs were analyzed separately: $GoRT_{RP}$, $StRT_{RP}$ (reaction time for repeated consecutive Go and Stop trials, respectively), $GoRT_{SW}$ and $StRT_{SW}$ (reaction time for the first Go trial after Stop trial and vice versa, respectively). Data from one male and one female participant were excluded from further analysis of the SST as the results indicated that they failed to follow the instructions correctly. Both participants' RTs differed by 4 standard deviations from the average and the number of mistakes made was close to maximum. For $StRT_{RP}$ $N = 44$, as some participants did not make the mistake of reacting to second consecutive Stop trials, therefore the respective indicator could not be calculated.

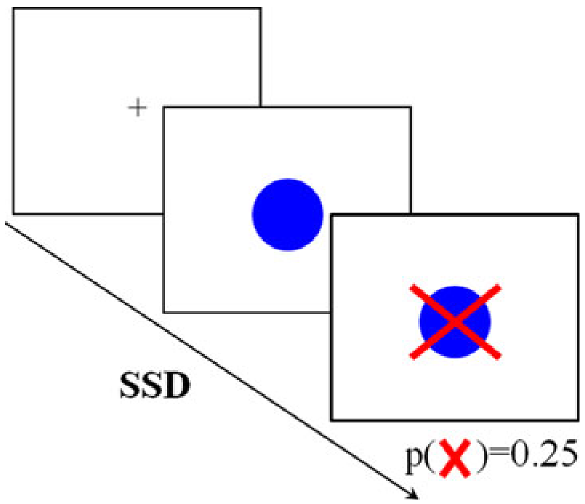

Fig. 1. Schematic presentation of stimuli in the Stop Signal Task.

Time estimation. Time estimation was measured by the retrospective verbal Time Estimation Task (TET). TET items were presented and timed as slides in a presentation program (OpenOffice 3.1). After practicing with the first three very simple slides of the version of the Visual Patterns Test (Della Sala *et al*., 1997) requiring reproduction of a pattern consisting of black and white squares, the subjects were asked to estimate how long they thought each individual slide, actually lasting 3 s, had stayed on the screen. Participants had no information about the TET beforehand. A similar design has been used in previous studies by Lennings & Burns (1998) and Khan, Sharma & Shikha (2006).

RESULTS

Table 1 lists mean results of the tasks for the whole group and for men and women separately.

Sex differences

Although the analysis of sex differences was not the main goal of the study, we look at them to exclude gender as a confounding factor in further analyses. There were no sex differences in the results of the SST. However, the independent samples *t*-test revealed significant sex differences in the TET and in self-reported impulsivity (see Table 1): (a) men tended to estimate the interval duration of 3 s to be significantly shorter than women; (b) women reported significantly lower scores on Excitement Seeking (AMIS-E) and Fast Decision-Making (AMIS-F) scales.

Stop Signal Task

As it was predicted by the Horse-Race Model (Logan & Cowan, 1984), the mean median StRT was significantly shorter than mean median GoRT ($t(55) = 11.4$, $p < 0.001$). Average values for the GoRT, StRT, SSRT, and SSD were comparable to previous results (Aron & Poldrack, 2006; Band et al., 2003; Sylwan, 2004).

Relationship between indicators of impulsivity

For variables showing significant sex differences, partial correlations, controlling for sex, were calculated. Results indicate the following: (1) there were no significant correlations between the results of the AMIS and the performance on the SST in traditional indicators of performance; (2) speed of inhibition processes (SSRT) is more related to performance in Stop trials than in Go trials; (3) adaptive (AMIS-E, AMIS-F) and maladaptive (AMIS-

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Table 1. *Means and sex differences in impulsivity measures used*

				Men			Women					
	N	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*	df	*t*	*p*
GoOK	56	0.98	0.03	29	0.98	0.03	27	0.98	0.02	54	−0.51	0.612
StOK	56	0.71	0.14	29	0.74	0.14	27	0.69	0.13	54	1.4	0.169
GoRT	56	505.1	115.1	29	523.8	129.7	27	484.9	95.5	54	1.27	0.209
StRT	56	419.4	87.8	29	440.8	98.6	27	396.4	69.1	54	1.94	0.058
GoRT$_{RP}$	57	519.9	123.4	29	534.0	134.7	28	505.4	111.0	55	0.87	0.386
StRT$_{RP}$	44	409.8	92.1	23	414.6	109.5	21	404.4	70.6	42	0.36	0.718
GoRT$_{SW}$	57	485.6	107.3	29	500.6	123.7	28	470.0	86.6	55	1.08	0.286
StRT$_{SW}$	57	415.5	88.7	29	434.1	98.0	28	396.2	74.8	55	1.63	0.106
SSD	56	358.7	129.1	29	379.1	133.6	27	336.8	122.8	54	1.23	0.224
SSRT	56	146.4	49.1	29	144.7	51.2	27	148.1	47.7	54	−0.26	0.799
TET	*56*	*2.9*	*1.3*	*28*	*2.5*	*1.0*	*28*	*3.3*	*1.4*	*54*	*−2.5*	*0.016**
AMIS-E	*51*	*21.1*	*4.9*	*23*	*23.2*	*4.9*	*28*	*19.4*	*4.3*	*49*	*2.96*	*0.004**
AMIS-I	52	18.0	5.2	24	17.1	5.3	28	18.8	5.1	50	−1.15	0.257
AMIS-F	*52*	*16.9*	*4.8*	*24*	*18.8*	*5.0*	*28*	*15.4*	*3.8*	*50*	*2.78*	*0.008**
AMIS-D	51	14.7	4.8	24	13.4	3.1	27	15.8	5.5	49	−1.88	0.067

Notes: GoOK and StOK are given in probability for correct responses in Go and Stop trials, respectively; RT refers to respective reaction time in ms, $_{RP}$ – repetitive trials, $_{SW}$ – switch trials, SSD is final average stop signal delay, SSRT is the stop signal reaction time (both in ms), TET is the verbal retrospective time estimation in seconds. For AMIS-E – Excitement seeking, AMIS-I – Disinhibition, AMIS-F – Fast Decision-Making and AMIS-D – Thoughtlessness are subscales of Adaptive and Maladaptive Impulsivity Scale.
* and italics are for $p < 0.05$.

Table 2. *Correlations between self-reported and laboratory behavioral impulsivity measures*

	GoOK	StOK	GoRT	StRT	GoRT$_{RP}$	StRT$_{RP}$	GoRT$_{sw}$	StRT$_{sw}$	SSD	SSRT	TET	AMIS-E	AMIS-I	AMIS-F
GoOK	–													
StOK	−0.63**	–												
GoRT	−0.77**	0.93**	–											
StRT	−0.57**	0.87**	0.88**	–										
GoRT$_{RP}$	−0.76**	0.95**	0.99**	0.88**	–									
StRT$_{RP}$	−0.30	0.50*	0.59**	0.69**	0.62**	–								
GoRT$_{SW}$	−0.74**	0.89**	0.97**	0.83**	0.95**	0.65**	–							
StRT$_{SW}$	−0.60**	0.91**	0.90**	0.98**	0.91**	0.64**	0.87**	–						
SSD	−0.63**	0.99**	0.93**	0.86**	0.94**	0.50*	0.88**	0.90**	–					
SSRT	−0.18	−0.44*	−0.09	−0.20	−0.18	−0.08	−0.08	−0.28*	−0.46**	–				
TET	0.27	−0.36*	−0.42*	−0.37*	−0.31*	−0.27	−0.35*	−0.25	−0.37*	−0.01	–			
AMIS-E	0.11	−0.04	−0.16	−0.14	−0.19	−0.43*	−0.18	−0.18	−0.04	−0.26	0.04	–		
AMIS-I	0.22	−0.22	−0.24	−0.26	−0.24	−0.20	−0.23	−0.24	−0.20	−0.04	0.20	0.01	–	
AMIS-F	0.08	−0.07	−0.07	0.04	−0.19	−0.35*	−0.22	−0.14	−0.06	0.01	0.20	0.54**	0.07	–
AMIS-D	−0.07	−0.01	−0.07	−0.08	−0.08	−0.25	−0.05	−0.05	0.00	−0.16	0.35*	0.15	0.53**	0.24

Notes: GoOK and StOK are given in probability for correct responses in Go and Stop trials, respectively; RT refers to respective reaction time in ms, $_{RP}$ – repetitive trials, $_{SW}$ – switch trials, SSD is final average stop signal delay, SSRT is the stop signal reaction time (both in ms), TET is the verbal retrospective time estimation in seconds. AMIS-E – Excitement seeking, AMIS-I – Disinhibition, AMIS-F – Fast Decision-Making and AMIS-D – Thoughtlessness are subscales of Adaptive and Maladaptive Impulsivity Scale.
** $p < 0.001$; * $p < 0.05$; N = 44–56 depending on missing data. For variables showing sex differences, partial correlations are provided (see Table 1 for sex differences).

D, AMIS-I) aspects of impulsivity were independent, as indicated by the lack of significant correlations between respective scales; (4) detailed analysis of the SST showed that AMIS-F and AMIS-E, both measuring adaptive impulsivity, are significantly correlated to StRT$_{RP}$; (5) time perception was correlated with both of the impulsivity measures – TET was positively correlated to Thoughtlessness (AMIS-D) and negatively correlated to several SST indicators (see Table 2). These linear relations were around |0.35| to |0.40| and can be considered modest in size.

The correlation matrix was further analyzed factor-analytically (varimax normalized extraction of principal components). The results show (see Table 3) that two factors, first including most of the SST impulsivity indicators (Behavioral Excitation and Inhibition) and second all AMIS scales (Self-Reported Impulsivity), explain 64.8% of total variance in the data. However, Table 3 also shows that the segregation into Behavioral Excitation and Inhibition and Self-Reported Impulsivity factors is not perfect: SSRT, the indicator of speed of inhibitory processes in the SST, fits into both factors, but more appropriately into the Self-Reported Impulsivity factor. The same is evident for TET, also a laboratory behavioral measure. The factor analysis demonstrates that there is something special about the repetitive Stop

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Table 3. *Factor-analyzed correlation matrix*

Variable	Factor 1*	Factor 2**
GoOK	**−0.71**	0.14
StOK	**0.97**	0.06
GoRT	**0.97**	−0.15
StRT	**0.93**	−0.10
$GoRT_{RP}$	**0.97**	−0.15
$StRT_{RP}$	**0.59**	**−0.50**
$GoRT_{SW}$	**0.93**	−0.20
$StRT_{SW}$	**0.94**	−0.09
SSD	**0.98**	0.07
SSRT	−0.32	**−0.49**
TET	−0.35	**0.42**
AMIS-E	−0.07	**0.63**
AMIS-I	−0.22	**0.41**
AMIS-F	−0.05	**0.63**
AMIS-D	0.01	**0.63**

Notes: GoOK and StOK are given in probability for correct responses in Go and Stop trials, respectively; RT refers to respective reaction time in ms, $_{RP}$ – repetitive trials, $_{SW}$ – switch trials, SSD is final average stop signal delay, SSRT is the stop signal reaction time (both in ms), TET is the verbal retrospective time estimation in seconds. AMIS-E – Excitement seeking, AMIS-I – Disinhibition, AMIS-F – Fast Decision-Making and AMIS-D – Thoughtlessness are subscales of Adaptive and Maladaptive Impulsivity Scale. Factor 1 - Behavioral Excitation and Inhibition, Factor 2 - Self-Reported Impulsivity.
* Total variance explained 0.50, ** Total variance explained 0.14,
Bold = factor loadings >0.40.

responses (StRTRP) as the parameter fits almost equally into both factors.

We also ran a multiple regression analysis (forward stepwise method) to predict TET from four subscales of the AMIS and two main indicators of performance in the SST: speed of Go processes (GoRT) and speed of inhibition (SSRT). As there was a significant gender difference in the results of the TET, sex was entered as a categorical predictor. A significant model was achieved ($F(3,45) = 8.45$, $p < 0.00015$) with an adjusted $R^2 = 0.32$, AMIS-D and GoRT as independent predictors (standardized regression coefficients 0.33 and −0.39, respectively).

DISCUSSION

Current study examined the relationship between different impulsivity measures. In addition to traditional ways of interpreting the results, we analyzed our data on a more detailed level. *The results indicate that self-reported impulsivity (AMIS) and excitatory and inhibitory processes (SST) are largely unrelated*. Similar results have also been reported earlier (e.g., Gebring, Ahadi & Patton, 1987). Based on these findings, it is fairly easy to agree that laboratory behavioral measures represent a slightly different aspect of impulsivity than self-report questionnaires (White, Moffitt, Caspi, Bartusch, Needles & Stouthamer-Loeber, 1994). On the basis of conventional parameters, we can say that we have measured at least four different types of impulsive behavior – adaptive and maladaptive in the self-descriptions together with excitatory and inhibitory processes in cognitive tasks (see Table 2). However, when analyzing the data provided by the SST in a more detailed way, it seems that self-reported impulsivity and laboratory behavioral measures of impulsivity might be related after all.

Looking at the after-effects of repeated and switch Go and Stop trials, scores obtained on Adaptive Impulsivity scales AMIS-E and AMIS-F were related to $StRT_{RP}$. *Participants with higher level of Adaptive Impulsivity had faster RTs to second consecutive Stop trials.* The result may reflect adaptively impulsive participants' response bias for the rewarded alternative (Smillie & Jackson 2006). The Fast Decision-Making scale used in the current study is inspired by and conceptually the same as Dickman's (1990) FI used by Smillie and Jackson (2006), and the result is in line with their suggestions of FI being conceptually similar to Gray's reward reactivity. The correlation with $StRT_{RP}$ might reflect that the participants who were functionally impulsive or had fast decision-making abilities learned that the probability of two consecutive Stop trials was very low or almost non-existent. Hence it was more useful or rewarding for them to quickly respond after seeing a Stop trial. This result is in line with the findings that subjects change responding strategies reactively after the occurrence of the stop signal (Verbruggen & Logan, 2008b). A conceptually similar result has been found by Correa *et al*. (2010) who reported that sequential effects in the Go/No-Go Task facilitated RTs to go condition and false alarms to no-go condition in the low impulsivity group. They concluded that both excitatory and inhibitory processing might be enhanced concurrently, which in turn enables temporal preparation of fast and controlled responses. At this point it is important to remind that Go/No-Go and SST allow different kinds of response inhibition and they are not identical measures (Verbruggen & Logan, 2008a). The same explanations can be applied to subjects with higher levels of Excitement Seeking. However, as the SST used in the current study was not specifically constructed for studying after-effects and measuring $StRT_{RP}$, this finding deserves further investigation.

Cognitive tempo, as measured by TET, was related to both types of impulsivity measures – to AMIS-D subscale and several SST indicators. Subjects with a higher level of Thoughtlessness, a scale inspired by Dickman's (1990) concept of DI, overestimated the duration of a 3-second period. This may be a result of having a faster cognitive tempo or accumulation of temporal pulses. The similar finding has been reported by Correa *et al*. (2010), who found that the healthy participants with higher levels of impulsivity produced longer time intervals compared to low Impulsivity participants. In addition to one Maladaptive Impulsivity scale, TET was negatively correlated to several SST indicators. The longer the estimated duration of a 3-second period, the faster the participant's reaction to the occurrences of Go trials (GoRT, $GoRT_{RP}$ and $GoRT_{sw}$) and the higher the probability of erroneously reacting to a Stop trial. A significant correlation also emerged between TET and SSD – the longer the time interval was rated to last, the shorter was the delay of the stop signal by the end of the task. Thus, the subjective perception of time duration (or cognitive tempo) could be a suitable candidate for a general mechanism behind all three, the stopping (Verbruggen & Logan, 2008a), the ''shooting'' performance (i.e., quick responding), and dysfunctional decisions in daily life.

Two independent measures of impulsivity, AMIS-D and GoRT, explained about 32% of the variability in TET – considerably more than each variable alone. The question of which aspect of temporal interval perception – the pace-maker, the accumulator or

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memory (Staddon, 2005; Wittmann & Paulus, 2008) – is exactly responsible for the reported relations, remains open.

Substantially similar results proving that TET has something in common with both types of measures, laboratory behavioral and self-reported impulsivity measures, were obtained by the factor analysis. TET loaded almost equally into both two factors, first consisting of SST measures, and second of AMIS subscales. As it has been previously found that impulsive people have an altered sense of time and they tend to overestimate time duration (Wittmann & Paulus, 2008), the belonging of TET into the same factor with self-reported impulsivity is not an unexpected finding. At first it seems surprising that the $StRT_{RP}$ is also loading to the factor of self-reported impulsivity, but this might be caused by the same reasons as the correlation between Adaptive Impulsivity and $StRT_{RT}$.

In the context where it is debatable whether FI can be considered ''impulsivity'' or should be named reward sensitivity instead (Franken & Muris, 2006; Smillie & Jackson, 2006), the results showing no relationship between Adaptive and Maladaptive impulsivity scales and their different relationship to other measures used may as well indicate that both are distinct constructs or at least different impulsivities measured by a self-report questionnaire. Therefore it is possible that these constructs might also have different underlying basis, one in the reward reactivity as proposed by the RST (Smillie & Jackson, 2006) and the other in time perception as indicated by the results of the current study, respectively.

In addition to a common finding that laboratory behavioral measures and self-report impulsivity tap largely independent sources of variability, we managed to demonstrate a meaningful pattern of correlations between different measures. If one assumes that stable individual differences must have roots in some fairly basic and multimodal neural processes, cognitive tempo seems a very promising candidate as one of the substrates of impulsivity. Relatively faster passage of time on a few-second-scale can explain faster responding in tasks measuring RTs as well as the average tendency to prefer immediate albeit smaller rewards over delayed larger ones. Such relative acceleration may apparently have consequences often reflected by different kinds of impulsivity measures – laboratory behavioral measures and self-report questionnaires. In summary, our study shows that the subjective time perception and stimulus after-effects deserve more attention as possible indicators of impulsivity.

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REFERENCES

Aron, A. & Poldrack, R. (2006). Cortical and subcortical contributions to stop signal response inhibition: role of subthalamic nucleus. *The Journal of Neuroscience*, *26*, 2424–2433.

Band, G., van der Molen, M. & Logan, G. (2003). Horse-race model simulations of the stop-signal procedure. *Acta Psychologica*, *112*, 105–142.

Barratt, E. (1993). Impulsivity: Integrating cognitive, behavioral, biological, and environmental data. In W. McCown, J. Johnson & M. Shure (Eds.), *The impulsive client: Theory, research, and treatment* (pp. 39–56). Washington, DC: American Psychological Association.

Berlin, H., Rolls, E. & Kischka, U. (2004). Impulsivity, time perception, emotion and reinforcement sensitivity in patients with orbitofrontal cortex lesions. *Brain*, *127*, 1108–1126.

Blaszczynski, A., Steel, Z. & McConaghy, N. (1997). Impulsivity in pathological gambling: The antisocial impulsivist. *Addiction*, *92*, 75–87.

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Bosco, A., Longoni, A. M. & Vecchi, T. (2004). Gender effects in spatial orientation: Cognitive profiles and mental strategies. *Applied Cognitive Psychology*, *18*, 519–532.

Butler, G. K. L. & Montgomery, A. M. J. (2005). Subjective self-control and behavioral impulsivity coexist in anorexia nervosa. *Eating Behaviors*, *6*, 221–227.

Cloninger, C., Przybeck, T. & Švarkić, D. (1991). The tridimensional personality questionnaire: U.S. normative data. *Psychological Reports*, *69*, 1047–1057.

Colder, C. & Chassin, L. (1997). Affectivity and impulsivity: temperament risk for adolescent alcohol involvement. *Psychology of Addictive Behaviors*, *11*, 83–97.

Correa, Á., Triviño, M., Pérez-Dueñas, C., Acosta, A. & Lupiáñez, J. (2010). Temporal preparation, response inhibition and impulsivity. *Brain & Cognition*, *73*, 222–228.

Costa, P. & McCrae, R. (1989). *The NEO-PI/NEO-FFI manual supplement*. Odessa, FL: Psychological Assessment Resources.

Costa, P. & McCrae, R. (1992). Normal personality assessment in clinical practice: The NEO personality inventory. *Psychological Assessment*, *4*, 5–13.

Della Sala, S., Gray, C., Baddeley, A. D. & Wilson, L. (1997). *Visual pattern test*. Bury St Edmunds, UK: Thames Valley Test Company.

Dickman, S. (1990). Functional and dysfunctional impulsivity: personality and cognitive correlates. *Journal of Personality and Social Psychology*, *58*, 95–102.

Dougherty, D., Mathias, C., Marsh, D. & Jagar, A. (2005). Laboratory behavioral measures of impulsivity. *Behavior Research Methods, Instruments & Computers*, *37*, 82–90.

Dougherty, D., Bjork, J., Harper, R., Mathias, C., Moeller, F. & Marsh, D. (2003). Validation of the immediate and delayed memory tasks in hospitalized adolescents with disruptive behavior disorders. *The Psychological Record*, *53*, 509–532.

Eensoo, D., Harro, M., Pullmann, H., Allik, J. & Harro, J. (2007). Association of traffic behavior with personality and palatelet monoamine oxidase activity among schoolchildren. *Journal of Adolescent Health*, *40*, 311–317.

Eensoo, D., Paaver, M., Pulver, A., Harro, M. & Harro, J. (2004). Low platelet MAO activity associated with high dysfunctional impulsivity and antisocial behavior: Evidence from drunk drivers. *Psychopharmacology*, *172*, 356–358.

Enticott, P., Ogloff, J. & Bradshaw, J. (2006). Associations between laboratory measures of executive inhibition control and self-reported impulsivity. *Personality and Individual Differences*, *41*, 285–294.

Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology*, *146*, 348–361.

Eysenck, S., Pearson, P., Easting, G. & Allsopp, J. (1985). Age norms for impulsiveness, venturesomeness and empathy in adults. *Personality and Individual Differences*, *6*, 613–619.

Franken, I. H. A. & Muris, P. (2006). Gray's impulsivity dimension: A distinction between Reward Sensitivity versus Rash Impulsiveness. *Personality and Individual Differences*, *40*, 1337–1347.

Gebring, D., Ahadi, S. & Patton, J. (1987). Toward a conceptualization of impulsivity: components across the behavioral and self-report domains. *Multivariate Behavioral Research*, *22*, 357–379.

Goldberg, L. R. (1999). A broad-bandwidth, public domain, personality inventory measuring the lower-level facets of several five-factor models. In I. Mervielde, I. Deary, F. De Fruyt & F. Ostendorf (Eds.), *Personality psychology in Europe* (pp. 7–28). Tilburg: Tilburg University Press.

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Gorlyn, M., Keilp, J., Tryon, W. & Mann, J. (2005). Performance test correlates of component factors of impulsiveness. *Personality and Individual Differences*, *38*, 1549–1559.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K. & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, *30*, 425–447.

Horn, N., Dolan, M., Elliott, R., Deakin, J. & Woodruff, P. (2003). Response inhibition and impulsivity: An fMRI study. *Neuropsychologia*, *41*, 1959–1966.

Khan, A., Sharma, N. K. & Shikha, D. (2006). Effect on cognitive load and paradigm on time perception. *Journal of the Indian Academy of Applied Psychology*, *32*(1), 37–42.

King, J., Tenney, J., Rossi, V., Colamussi, L. & Burdick, S. (2003). Neural substrates underlying impulsivity. *Annals of the New York Academy of Sciences*, *1008*, 160–169.

Lennings, C. J. & Burns, A. M. (1998). Time perspective: Temporal extension, time estimation, and impulsivity. *Journal of Psychology: Interdisciplinary and Applied*, *132*(4), 367–380.

Logan, G. & Cowan, W. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*, 295–327.

Logan, G. D., Schachar, R. J. & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science*, *8*(1), 60–64.

Moeller, F., Barratt, E., Dougherty, D., Schmitz, J. & Swann, A. C. (2001). Psychiatric aspects of impulsivity. *American Journal of Psychiatry*, *158*, 1783–1793.

Monsell, S. (2003). Task-switching. *Trends in Cognitive Sciences*, *7*, 134–140.

Mõttus, R., Pullmann, H. & Allik, J. (2006). Towards more readable Big Five personality inventories. *European Journal of Psychological Assessment*, *22*, 149–157.

Paaver, M., Eensoo, D., Pulver, A. & Harro, J. (2006). Adaptive and maladaptive impulsivity, palatelet monoamine oxidase (MAO) activity and risk-admitting in different types of risky drivers. *Psychopharmacology*, *186*, 32–40.

Paaver, M., Kurrikoff, T., Nordquist, N., Oreland, L. & Harro, J. (2008). The effect of 5-HTT gene promoter polymorphism on impulsivity depends on family relations in girls. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *32*, 1263–1268.

Patton, J. H., Stanford, M. S. & Barratt, E. S. (1995). Factor structure of the Barratt impulsiveness scale. *Journal of Clinical Psychology*, *51*, 768–774.

Reynolds, B., Ortengren, A., Richards, J. & de Wit, H. (2006). Dimensions of impulsive behavior: Personality and behavioral measures. *Personality and Individual Differences*, *40*, 305–315.

Rieger, M. & Gauggel, S. (1999). Inhibitory after-effects in the stop signal paradigm. *British Journal of Psychology*, *90*, 509–518.

Schachar, R. J., Chen, S., Logan, G. D., Ornstein, T. J., Crosbie, J., Ickowicz, A. & Pakulak, A. (2004). Evidence for an error monitoring deficit in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology*, *32*(2), 285–293.

Schachar, R. & Logan, G. (1990). Impulsivity and inhibitory control in normal development and childhood psychopathology. *Developmental Psychology*, *26*, 710–720.

Simonson, E. & Brozek, J. (1952). Flicker fusion frequency: Background and applications. *Physiological Reviews*, *32*, 349–378.

Smillie, L. D. & Jackson, C. J. (2006). Functional impulsivity and reinforcement sensitivity theory. *Journal of Personality*, *74*(1), 1–37.

Staddon, J. (2005). Interval timing: memory, not a clock. *Trends in Cognitive Sciences*, *9*, 312–314.

Swann, A., Bjork, J., Moeller, G. & Dougherty, D. (2002). Two models of impulsivity: Relationship to personality traits and psychopathology. *Biological Psychiatry*, *51*, 988–994.

Swick, D., Ashley, V. & Turken, A. U. (2011). Are the neural correlates of stopping and not going identical? Quantitative meta-analysis of two response inhibition tasks. *Neuroimage*, *56*, 1655–1665.

Sylwan, R. (2004). The control of deliberate waiting strategies in a stop-signal task. *Brazilian Journal of Medical and Biological Research*, *37*, 853–862.

Verbruggen, F., Liefooghe, B. & Vandierendonck, A. (2005). On the difference between response inhibition and negative priming: evidence from simple and selective stopping. *Psychological Research*, *69*, 262–271.

Verbruggen, F. & Logan, G. (2008a). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General*, *137*(4), 649–672.

Verbruggen, F. & Logan, G. (2008b). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, *12*, 418–424.

Vigil-Colet, A. & Codorniu-Raga, M. (2004). Aggression and inhibition deficits: The role of functional and dysfunctional impulsivity. *Personality and Individual Differences*, *37*, 1431–1440.

White, J., Moffitt, T., Caspi, A., Bartusch, D., Needles, D. & Stouthamer-Loeber, M. (1994). Measuring impulsivity and examining its relationship to delinquency. *Journal of Abnormal Psychology*, *103*, 192–205.

Whiteside, S. & Lynam, R. (2001). The Five Factor Model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences*, *30*, 669–689.

Wittmann, M., Leland, D., Churan, J. & Paulus, M. P. (2007). Impaired time perception and motor timing in stimulant-dependent subjects. *Drug and Alcohol Dependence*, *90*, 183–192.

Wittmann, M. & Paulus, M. P. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, *12*, 7–12.

Zuckerman, M. (1994). *Behavioral expressions and biosocial bases of sensation seeking*. New York: Cambridge University Press.

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