Research Report

IMPULSIVITY AND INHIBITORY CONTROL

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Abstract—*We report an experiment testing the hypothesis that impulsive behavior reflects a deficit in the ability to inhibit prepotent responses. Specifically, we examined whether impulsive people respond more slowly to signals to inhibit (*stop signals*) than nonimpulsive people. In this experiment, 136 undergraduate students completed an impulsivity questionnaire and then participated in a stop-signal experiment, in which they performed a choice reaction time (go) task and were asked to inhibit their responses to the go task when they heard a stop signal. The delay between the go signal and the stop signal was determined by a tracking procedure designed to allow subjects to inhibit on 50% of the stop-signal trials. Reaction time to the go signal did not vary with impulsivity, but estimated stop-signal reaction time was longer in more impulsive subjects, consistent with the hypothesis and consistent with results from populations with pathological problems with impulse control.*

Impulsivity is an important construct in several domains. In personality theory, it is part of the construct of extraversion (Eysenck & Eysenck, 1969; Revelle, Humphreys, Simon, & Gilliland, 1980). In childhood psychopathology, it is part of the construct of attention deficit hyperactivity disorder (ADHD) and conduct disorder (Quay, 1988). And in adult psychopathology, it is an important characteristic of psychopathic and sociopathic personalities (Gorenstein & Newman, 1980; Patterson & Newman, 1993). We have found it useful to operationalize impulsivity in terms of the ability to inhibit prepotent courses of action: People who are impulsive have trouble inhibiting action, whereas people who are not impulsive find it easier to do so. We found support for this hypothesis in studies of children with ADHD. They had more trouble inhibiting prepotent actions than control children with other psychiatric diagnoses and control children with no apparent psychopathology (for a review, see Schachar, Tannock, & Logan, 1993). Moreover, the inhibitory difficulties of children with ADHD were ameliorated by administration of stimulant medication (methylphenidate), which also improves behavioral symptoms of ADHD (including impulsivity; Tannock, Schachar, Carr, Chajcyzk, & Logan, 1989; Tannock, Schachar, & Logan, 1995). The purpose of the present article is to examine the relation between impulsivity and inhibitory control in young adults with no psychiatric diagnoses.

THE STOP-SIGNAL PARADIGM

Our measure of inhibitory control comes from the *stop-signal paradigm* (Lappin & Eriksen, 1966; Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984; Ollman, 1973; Osman, Kornblum, & Meyer, 1986, 1990; Vince, 1948). The paradigm involves two concurrent tasks, a *go task* and a *stop task*. The go task is a choice reaction time task that requires subjects to discriminate an *X* from an *O*. The stop task, which occurs on 25% of go-task trials, involves presentation of a tone (a stop signal) that tells subjects to inhibit their response to the go task on that trial. Whether or not subjects are able to inhibit depends on a race between the stop task and the go task: If they finish the stop task before the go task, they inhibit their response to the go task. However, if they finish the go task before the stop task, they fail to inhibit their response to the go task, responding much as they would if no stop signal had been presented. Thus, inhibitory control depends on the latency of the response to the go signal (*go reaction time*) and the latency of the response to the stop signal (*stop-signal reaction time*). The race model has been developed formally and shown to be able to account quantitatively for all of the data in stop-signal experiments (Logan & Cowan, 1984; Osman et al., 1986; for a review, see Logan, 1994).

We treat the stop-signal paradigm as a model of inhibitory control of an impulse. We interpret the go signal as the impetus for the impulse, and we interpret the response to the go signal as the prepotent response. The stop signal is a control signal that makes the prepotent response inappropriate. In the real world, the stop signal may come from an external source, like a teacher or a stoplight, or from an internal source, like the person's reevaluation of the situation. In the laboratory, it comes from an external source (the computer) that is under the control of the experimenter. From this perspective, inhibiting when given a stop signal is evidence of good impulse control, and failing to inhibit when given a stop signal is evidence of poor impulse control.

According to the race model, poor inhibitory control could result from responding too quickly to the go signal or responding too slowly to the stop signal. Fast responses to the go signal would be executed before the person could respond to the stop signal, and slow responses to the stop signal would allow normally speeded responses to the go signal to escape inhibition. Our studies of ADHD children suggest that slow stop-signal reaction time is responsible for poor impulse control. Children with ADHD inhibit less often than control children even though their go-signal reaction times are longer than control children's. Children with ADHD exhibit disproportionately longer stop-signal reaction times and therefore inhibit less often (Schachar & Logan, 1990; Schachar, Tannock, Marriott, & Logan, 1995). Thus, one might expect that long stop-signal reaction times are responsible for inhibitory control deficits in other populations with impulse control problems (i.e., young impulsive adults).

MEASURING STOP-SIGNAL REACTION TIME

Unlike go-signal reaction time, stop-signal reaction time cannot be measured directly. Subjects either inhibit or fail to inhibit when a stop signal is presented. If they fail to inhibit, stop-signal reaction time must have been slower than the observable latency of the go-signal response, but it is not clear how much slower it was If they success in inhibiting, stop-signal reaction time must have been faster than go-signal reaction time, but neither the stop process nor the go process

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provides an observable response with a measurable latency. Something beyond direct observation is required.

The race model of the stop-signal paradigm provides at least three different ways to estimate stop-signal reaction time (see Logan, 1994). The methods are relatively complex and require a deep understanding of the race model (at the level of reaction time distributions). The purpose of this article, in part, is to introduce a fourth method for estimating stop-signal reaction time, also derived from the race model, that is easier to compute and much easier to understand than the other methods.

In stop-signal experiments, researchers vary the delay between the stop signal and the go signal (*stop-signal delay*) in order to handicap the race in favor of one process or the other. Most often, stop-signal delays are selected at random from a fixed set that is held constant throughout the experiment (e.g., Logan & Cowan, 1984), but many researchers let them vary dynamically, contingent on the subject's behavior (e.g., Osman et al., 1986, 1990; Schachar & Logan, 1990; Schachar et al., 1995). The new method for estimating stop-signal reaction time uses a tracking procedure in which stop-signal delay changes after every stop-signal trial, increasing by 50 ms if subjects inhibit and decreasing by 50 ms if they respond. This tracking procedure, introduced by Osman et al. (1986, 1990), converges on a stop-signal delay at which signals inhibit 50% of the time. That delay is important because it represents the amount of handicapping necessary to "tie" the race. At that delay, the stop process and the go process finish at the same time, on average, and the one that happens to win on a particular trial depends on random variation. Thus, that delay is the average point in time at which the stop process finishes, and that information can be used to estimate stop-signal reaction time.

The estimation of stop-signal reaction time is illustrated in Figure. 1. The race depends on three quantities—go reaction time, stop-signal reaction time, and stop-signal delay—and the experimenter knows two of them. Moreover, because subjects inhibit 50% of the time at the critical delay, stop-signal reaction time plus stop-signal delay must equal mean go reaction time. Stop-signal reaction time can be calculated simply by subtracting stop-signal delay from mean go reaction time.

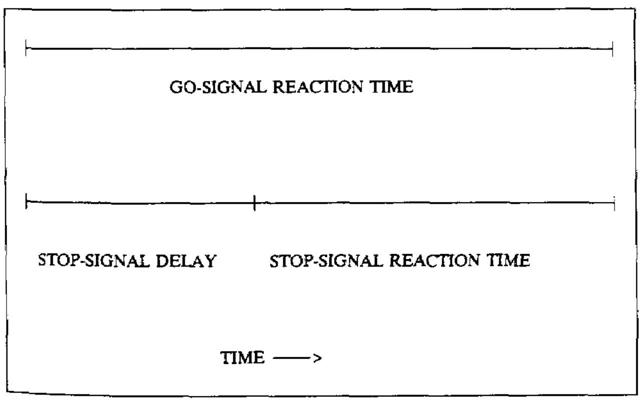

Fig. 1. How to estimate stop-signal reaction time. The top line represents mean reaction time to the go signal. The bottom line represents stop-signal delay plus stop-signal reaction time. Stop-signal delay is adjusted so that subjects inhibit 50% of the time, which means the race is tied. Therefore, the two lines end at the same point in time. Stop-signal reaction time, which is not directly observable, can be estimated by subtracting stop-signal delay, which is observable, from mean go-signal reaction time, which is also observable.

EXPERIMENT

We used the new method of estimating stop-signal reaction time to investigate the relation between impulsivity and inhibitory control in young adult subjects. We assessed impulsivity with the impulsivity subscale from the extraversion scale of the Eysenck Personality Inventory. This subscale gives an impulsivity score between 1 (low) and 9 (high). We expected subjects with higher impulsivity scores to have longer stop-signal reaction times.

Method

Subjects

The subjects were 136 students, 80 male and 56 female, who were in an introductory psychology laboratory course and volunteered their data for analysis.

Apparatus and stimuli

The stimuli were presented on IBM-compatible computers connected to a network. The stimuli for the go task were the letters *X* and *O* presented in the center of the screen for 1,000 ms. The *X* or *O* was preceded by a 500-ms fixation point, also presented in the center of the screen, and followed by a blank screen that was exposed for 1,000 ms. The stop signal was a 100-ms, 1000-Hz tone played through the internal speaker of the computer at the comfortable listening level. Stop-signal delay was set at 250 ms initially and then adjusted dynamically depending on the subject's behavior. The delay increased by 50 ms if the subject inhibited successfully (making it harder to inhibit on the next stop-signal trial) and decreased by 50 ms if the subject failed to inhibit (making it easier to inhibit on the next stop-signal trial).

The experimental task involved 512 trials administered in four 128-trial blocks. There were an equal number of *X*s and *O*s in each block. Stop signals were presented on 25% of the trials in each block (i.e., on 32 trials), half of the time with an *X* and half of the time with an *O*. The order in which trials were presented was randomized separately for each subject. Once started, the program ran continuously, presenting one trial every 2.5 s. It paused every 128 trials to allow subjects to rest.

The extraversion scale consisted of 22 true-false questions from the Eysenck Personality Inventory (Eysenck & Eysenck, 1969), 9 of which made up the impulsivity subscale and 13 of which made up a sociability subscale. The items were presented in a list format, with impulsivity and sociability items roughly alternating. The items were presented in the same order for each subject. The sociability items were treated as fillers and not analyzed further.

Procedure

Subjects were tested in groups of 10 to 15. The extraversion scale was administered to all subjects in a group at once. They were told it was a personality test and they were to decide whether each item described them, writing "true" beside the item if it did and "false" if it did not. After the test was completed, subjects scores their own tests under the experimenter's direction. Each subject produced two scores, an impulsivity score between 1 and 9 and a sociability score between 1 and 13.

After the personality test, the experimenter gave the instructions for the experimental task. The instructions described the go task first, telling subjects they would see a fixation point followed by a letter, and their task was to respond to the letter as quickly as possible without making errors, pressing the "/" key if the letter was an *X* and the "z" key if it was an *O*. Then the stop task was described. Subjects were told that occasionally they would hear a tone that told them not to respond on that trial. They were told to inhibit their response if they could but not to worry if thy were not able to inhibit. They were told that the stop signal would occur at different times, so sometimes they would be able to stop and sometimes they would not. They were told not to let the stop task interfere with the go task, and not to wait for the stop signal. After the instructions, subjects went into separate rooms to perform the experimental task.

Results

Averaged over all subjects, mean reaction time on the go task when no stop signals were presented was 557 ms and mean accuracy was 94%. The mean probability of responding on a stop-signal trial was .506, indicating that the tracking algorithm succeeded in converging on a delay that allowed subjects to inhibit half of the time. The mean delay was 336 ms, and the mean estimated stop-signal reaction time was 221 ms, which is typical of values observed in other studies with young adults (see the following section and Logan & Cowan, 1984). Impulsivity scores ranged from 1 to 9, averaging 4.39.

Measures of performance on the go and stop tasks are presented as a function of impulsivity score in Table 1. Mean go-signal reaction times and stop-signal reaction times are plotted as a function of impulsivity in Figure 2. Except for the extreme impulsivity scores, for which there were only a few subjects, go-signal reaction time appeared to decrease as impulsivity increased. Within-subject variability and accuracy remained relatively constant. The probability of responding given a signal did not change much across impulsivity levels, but stop-signal reaction time increased with impulsivity, consistent with our hypothesis. In order to keep the probability of re-

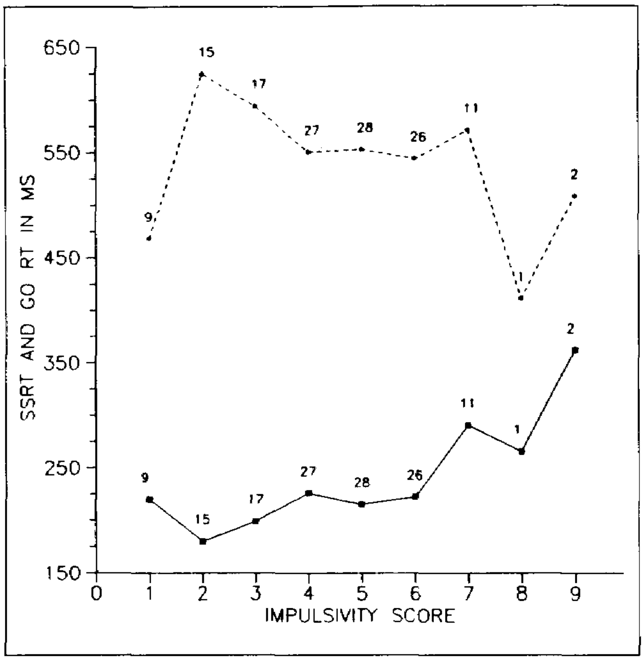

Fig. 2. Mean reaction time (RT) to the go signal (dotted line) and mean stop-signal reaction time (SSRT; solid line) as a function of impulsivity score. The number of subjects contributing to each point is written above each point.

sponding constant in the face of increasing stop-signal reaction times, the tracking algorithm set the mean delay lower for subjects with higher impulsivity scores (see Fig. 1).

We tested the significance of these trends in two ways. First, we computed Pearson product-moment correlations between impulsivity scores and the various performance measures. The correlation matrix is presented in Table 2. The only variable that correlated significantly with impulsivity was stop-signal reaction time. Mean go reaction time and mean stop-signal delay did not correlate significantly with impulsivity.

Table 1. *Measures of performance on the go and stop tasks and estimates of stop-signal reaction time as a function of impulsivity score*

	Impulsivity score								
Measure	1 (*n* = 9)	2 (*n* = 15)	3 (*n* = 17)	4 (*n* = 27)	5 (*n* = 28)	6 (*n* = 26)	7 (*n* = 11)	8 (*n* = 1)	9 (*n* = 2)
Go task									
Mean RT	468	625	594	550	552	543	570	410	507
SD of RT	101	145	125	128	128	133	146	99	151
P(C)	.96	.93	.92	.94	.97	.96	.86	.92	.95
Stop-signal delay									
Mean	248	445	395	324	337	321	281	145	146
SD	63	80	72	70	68	69	68	61	69
P(R|S)	.507	.476	.490	.515	.506	.496	.559	.555	.527
Stop-signal RT	220	180	199	226	215	222	289	265	361

Note. Standard deviations are within-subjects (i.e., deviations from each subject's mean). RT = reaction time; *P*(C) = proportion of correct responses; *P*(R|S) = probability of responding given a stop signal.

Table 2. *Correlations between impulsivity and the performance measures*

	Impulsivity	Go task: Mean RT	Go task: *SD* of RT	Go task: *P*(C)	Stop-signal delay: Mean	Stop-signal delay: *SD*	*P*(R|S)	Stop-signal RT
Go task								
Mean RT	−.036							
SD of RT	.073	.799						
P(C)	−.023	.003	−.098					
Stop-signal delay								
Mean	−.131	.951	.715	−.055				
SD	−.060	.846	.753	−.201	.849			
P(R|S)	.137	−.442	−.317	.027	−.573	−.579		
Stop-signal RT	.315	−.160	.017	.184	−.457	−.277	.558	
Mean	4.39	557	130	.94	336	70	.506	221
SD (between)	1.79	203	62	.12	226	23	.085	71

Note. $N = 136$. Correlations greater than .169 are significant at $p < .05$ (two-tailed), and correlations greater than .221 are significant at $p < .01$ (two-tailed); RT = reaction time; *P*(C) = proportion of correct responses; *P*(R|S) = probability of responding given a stop signal; *SD* (between) is the standard deviation of the scores between the subjects (i.e., deviations from the means across subjects).

Second, we split the subjects into two groups, half with impulsivity scores from 1 through 4 and half with impulsivity scores from 5 through 9. Measures of performance on the go task and stop task for the two groups are presented in Table 3. The only significant difference between the groups was stop-signal reaction time, which was faster in the low-impulsive subjects than in the high-impulsive subjects. Mean go-signal reaction time was faster in high-impulsive subjects than in low-impulsive subjects, but the difference was not significant.

VALIDITY OF THE NEW METHOD

We tested the validity of the new method by computing stop-signal reaction times with a conventional method and correlating those values with values from the new method. The conventional method (described in detail by Logan & Cowan, 1984, pp. 302–303, and Logan, 1994, pp. 215–217) involves estimating the point on the go-task reaction time distribution at which the stop process finished, and subtracting out stop-signal delay to calculate stop-signal reaction time (assuming that stop-signal reaction time is a constant). In practice, this method involves (a) rank ordering go reaction times from trials with no stop signals; (b) finding the *m*th go reaction time, where *m* is the product of the probability of responding given a stop signal at some delay and the number (n) of responses in the go-signal reaction time distribution (i.e., $m = P(\text{respond}|\text{signal})*n$); and (c) subtracting the given stop-signal delay from the *m*th reaction time.

We performed this procedure for each subject for every delay that provided a "reasonable" amount of data, defining "reasonable" in several different ways. We obtained the highest correlation between new-method and conventional-method stop-signal reaction times (r =

Table 3. *Measures of performance on the go and stop tasks for subjects with impulsivity scores above and below the median*

Measure	Below median score: Mean	Below median score: *SD*	Above median score: Mean	Above median score: *SD*	Inferential statistics: *t*(134)	Inferential statistics: *MSE*
Go task						
Mean RT	566	209	548	198	.517	34.98
SD of RT	127	60	133	64	−.529	10.61
P(C)	.94	.15	.95	.10	−.463	2.12
Stop-signal delay						
Mean	358	234	313	216	1.166	38.65
SD	72	24	68	22	.822	3.92
P(R|S)	.499	.073	.512	.095	−.902	.015
Stop-signal RT	208	67	235	72	−2.266	11.91

Note. Mean impulsivity score was 2.91 for subjects below the median and 5.87 for subjects above the median. $t(134) \geq 1.980$ is significant at $p < .05$ (two-tailed); $t(134) \geq 2.617$ is significant at $p < .01$ (two-tailed). RT = reaction time; *P*(C) = proportion of correct responses; *P*(R|S) = probability of responding given a stop signal.

.763) by analyzing delays that included 10 or more stop-signal trials and for which the probability of responding given the stop signal was between .1 and .9. With those criteria, 129 out of 136 subjects were included in the analysis. The mean conventional stop-signal reaction time was 199 ms (compared with 222 using the new method), and the correlation between conventional stop-signal reaction time and impulsivity was .187, $t(127) = 2.14$, $p < .05$, two-tailed.

We obtained the highest correlation between conventional stop-signal reaction time and impulsivity ($r = .252$, $t(131) = 2.98$, $p < .01$, two-tailed) by analyzing delays that included five or more stop-signals trials and for which the probability of responding given the stop signal was between .1 and .9. With these criteria, 133 out of 136 subjects contributed data. The mean stop-signal reaction time was 207 ms (compared with 217 ms using the new method), and the correlation between conventional and new stop-signal reaction time was .615.

We were surprised by the low correlations between the methods for calculating stop-signal reaction time, so we assessed the reliability of each method by calculating stop-signal reaction time separately for odd and even trials for each subject and correlating the values. For the new method, all 136 subjects contributed data and $r = .945$. For the conventional method, applied to delays that included five or more stop-signal trials with the probability of responding given a signal between .1 and .9, only 122 subjects contributed data and $r = .395$. This finding suggests that the low correlations between methods were due to unreliability in the conventional estimates. We suspect the unreliability of the conventional estimates may be due to some aspect of the tracking procedure, which was not designed to provide optimal estimates of conventional stop-signal reaction time. We are planning to test subjects with the new method and a version of the conventional method that is optimized for calculating conventional stop-signal reaction time to provide a more appropriate comparison between methods.

DISCUSSION

The results showed a significant relation between impulsivity and inhibitory control: High-impulsive subjects had longer stop-signal reaction times. This result corroborates our hypothesis that problems with impulse control stem from difficulties in inhibitory processing rather than extra facility in executing prepotent responses. That is, impulsive people appear to have difficulty inhibiting prepotent responses not because their prepotent responses are exceptionally fast, but rather because their inhibitory responses, which countermand and counteract the prepotent responses, are exceptionally slow.

Two factors mitigate these conclusions. First, go-task reaction times were faster for more impulsive subjects, though the difference was not significant. Perhaps a more sensitive experiment with a larger sample of extreme impulsivity scores would reveal a significant difference. Second, we used only one scale to define impulsivity, so it is not clear how well our results would generalize to other scales and other measures. Further research will be required to assess the generality of our conclusions.

Nevertheless, the results demonstrate the validity and feasibility of the new measure of stop-signal reaction time. It is easier to compute and to understand than previous methods, yet it produces similar values. The tracking procedure is easy to implement, and reliable estimates of the delay at which subjects inhibit half of the time can be gathered in a relatively short period of time. Thus, the modified stop-signal paradigm is a promising tool for future investigations of inhibitory control, within and beyond studies of impulsivity.

The experiment demonstrates the utility of the information processing approach to personality and psychopathology. This approach allows us to understand the characteristics of normal and abnormal personalities in terms of underlying cognitive processes. More generally, it allows us to see theoretical and empirical commonalities between areas of investigation that were hitherto separate (also see Gorenstein & Newman, 1980; Patterson & Newman, 1993).

Acknowledgments—This research was supported in part by Grants BNS 91-09856 and SBR 94-10406 to Gordon Logan from the National Science Foundation. We are grateful to Brian Compton for help in managing the computer network, Julie Delheimer for help in analyzing the data, and David Adams, Rachel Andrews, Brian Compton, Chris Currie, Heidi Homer, Emilie Lin, and Stan Taylor for testing the subjects. We would like to thank Bill Revelle for providing us with the impulsivity scale.

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(Received 8/23/95; Accepted 12/29/95)