Impulsivity and Speed-Accuracy Tradeoffs in Information Processing

Scott J. Dickman  
University of Texas at Austin

David E. Meyer  
University of Michigan

Despite its theoretical importance for such areas of research as reflection-impulsivity (Kagan, 1966), there is little evidence to support the assumption that individual differences in the personality trait of impulsivity are associated with differences in the willingness to sacrifice accuracy for speed in information processing. The present studies explored this association further. In Experiment 1, high, medium, and low impulsives (identified by self-report) performed a visual-comparison task under conditions differing in the monetary payoff for speed relative to accuracy. High impulsives were consistently faster and less accurate than other subjects. However, an analysis based on Sternberg’s (1969) additive-factor method indicated that high impulsives performed at least one stage of information processing as slowly and accurately as other subjects. In Experiment 2, it was found that high impulsives were actually more accurate than low impulsives when all subjects were required to process information extremely rapidly. Experiment 3 identified the response execution stage as one that high impulsives carry out just as slowly and accurately as other individuals. The data from these experiments pose problems for a simple speed-accuracy tradeoff model of impulsive cognitive functioning.

Is the personality trait of impulsivity associated with a preference for information-processing strategies that emphasize speed at the expense of accuracy? Given the general behavioral characteristics of impulsive individuals (i.e., their tendency to engage in rash actions), such an association is highly plausible. Yet, empirical confirmation of this association has been surprisingly difficult to obtain.

The most likely source of such evidence would seem to be the literature on reflection-impulsivity (e.g., Kagan, 1966; Kagan, Rosman, Day, Albert, & Phillips, 1964). In this body of research, subjects are categorized as “impulsive” on the basis of rapid and inaccurate performance on a task (the Matching Familiar Figures Test; MFFT) that requires them to decide which member of a set of figures is identical to a specified exemplar. A number of studies have examined the relationship between fast, inaccurate MFFT performance and the personality trait of impulsivity (as indexed by self-report inventories and behavioral observations). Block, Block, and Harrington (1974), reviewing this literature, concluded that these studies have failed to confirm the existence of such a relationship. There have been only a few isolated exceptions (e.g., Baron, Badgio, & Gaskins, 1985, found a relationship between behavior ratings of impulsivity and speed and accuracy on certain types of trials on an MFFT-like matching task).

There are several possible explanations for the difficulty that researchers have experienced in demonstrating a direct relationship between the personality trait of impulsivity and a particular willingness to sacrifice accuracy for speed in information processing. One possibility is simply that the behaviors typically used to infer the presence of the personality trait of impulsivity do not in fact reflect primarily the preference for fast, inaccurate performance. There is evidence that the trait of impulsivity has other components besides the tendency to act with little forethought (Eysenck & Eysenck, 1977). Perhaps one of these other components, such as enjoyment of taking risks, actually underlies the behaviors on which we rely most heavily in inferring that someone is impulsive.

A second possibility is that the personality and cognitive measures typically used to assess subjects’ bias toward speed or accuracy in information processing have not been sufficiently sensitive to detect a relationship between impulsivity and speed-accuracy tradeoffs. For example, researchers in the area of reflection-impulsivity have traditionally categorized a subject as impulsive when, on the MFFT, that subject has a response time below the median and an error rate above the median. At the other extreme, these researchers have categorized a subject as reflective when that subject has a response time above the median and an error rate below the median. The power of this approach is limited by at least two factors: (a) It leaves the impulsivity status of half the subjects (i.e., fast-accurate and slow-
inaccurate ones) indeterminate; and (b) any ability factors that affect the speed and accuracy of performance are confounded with strategy preferences.

A third possibility is that the trait of impulsivity has less cross-situational consistency than previous researchers have assumed to be the case. Kagan (1966) argued that differences between impulsive and reflective subjects will only manifest themselves in tasks in which there is much uncertainty about which response is correct. However, response uncertainty may not be the only important situational factor. The speed and accuracy of a subject's performance in any given situation could also depend on the payoff for speed relative to accuracy. Impulsivity-related performance differences may not appear when the situational pressure to be very fast or to be very accurate is strong (i.e., situations in which the payoff for speed is much greater than the payoff for accuracy, or vice versa).

The present work was designed to clarify further this relationship between personality and information processing. We have used more sensitive measures of strategy preferences than those used in previous research, and we have systematically varied payoffs for speed and accuracy. We have also drawn on reaction-time techniques used in current information-processing research (e.g., Lachman, Lachman, & Butterfield, 1979) in order to study the cognitive processes of impulsive individuals in a more detailed fashion than has been possible with the techniques traditionally used in the cognitive-style literature.

We had several aims in this research. First, we sought to obtain direct evidence for an association between individual differences in the personality trait of impulsivity and individual differences in the value placed on speed relative to accuracy of information processing. Second, we tried to assess the consistency across situations of impulsivity-related differences in information processing.

A third aim of this research was to determine whether the cognitive correlates of impulsivity reflect ability differences or stylistic differences. Is it always preferable to be at one end of this dimension rather than the other, as with an ability dimension, or do both ends of the continuum have advantages and disadvantages, as with a stylistic dimension?

Fourth, we examined the manner in which high, medium, and low impulsives carry out specific stages of information processing to determine whether similar impulsivity-related differences in speed and accuracy would appear at all stages. The performance of a cognitive task can include a variety of different processing stages, including stimulus encoding, memory retrieval, decision making, and response execution. One cannot assume that impulsivity-related speed and accuracy differences are necessarily consistent across stages of information processing, any more than one can assume that such processing differences are consistent across situations.

In order to examine the consistency of high, medium, and low impulsives' performance across stages of information processing, we have drawn on Sternberg's (1969) additive-factor method. It may be helpful to briefly review that method here.

Additive-Factor Method

Sternberg's (1969) additive-factor method is predicated on two assumptions: (a) The performance of mental tasks involves a sequence of discrete processing stages, and (b) the total time required to complete a task is simply the sum of the times required to complete each of the processing stages involved in that task.

Given these assumptions, inferences can be made about whether different factors (e.g., personality traits, experimental manipulations) influence the same or different stages of information processing. Figures 1 and 2 illustrate the possible relationships between factors and processing stages.

Under the stage model, when two factors influence different stages of processing, their combined effects on reaction time are additive; each factor increases or decreases the duration of a stage of processing, and the change in the duration of the stage
Raw accuracy data are in the form of the percentage of correct responses, which is equivalent to the probability that any given response is correct. The problem is that when a certain outcome depends on the occurrence of a sequence of independent events, the probability that outcome will occur equals the probability that the first event will occur, times the probability that the second event will occur, times the probability that the third event will occur, and so on—a multiplicative relationship. Thus, for an information-processing task, the probability that the final response is correct equals the probability that the output of the first stage of processing is correct, times the probability that the output of the second stage of processing is correct, times the probability that the output of the third stage of processing is correct, and so on. To use the additive-factor method, however, the effects of each stage on the final response measure must be additive.

Such additivity can be achieved simply by logarithmically transforming the raw percent-correct data. For any set of numbers, the logarithm of the product of those numbers is the sum of the logarithms of the numbers in the set; for example, $10 = 5 \times 2; \log(10) = \log(5) + \log(2)$. In the case of an information-processing task, the logarithm of the probability that the overall response is correct equals the sum of the logarithm of the probability that the output of Stage 1 is correct plus the logarithm of the probability that the output of Stage 2 is correct, and so on. This additive relationship meets the assumptions of Sternberg's (1969) method, and such logarithmically transformed accuracy data can therefore be analyzed just like reaction-time data (for further details, see Schweikert, 1984).

Relevance of Additive-Factor Method

For the present purposes, the additive-factor method provides a technique for determining which stages of processing are carried out differently by individuals differing in impulsivity; an experimental manipulation designed to influence such a stage would be expected to interact with impulsivity in determining overall response time and accuracy. Similarly, it is possible to determine, by means of the additive-factor method, which stages of processing are carried out identically by individuals differing in impulsivity; an experimental manipulation designed to influence such a stage would not show an interaction with impulsivity.

Limitations of the Additive-Factor Method

It is important to point out that certain assumptions of the additive-factor method have been challenged by McClelland (1979) and other theorists (e.g., Meyer, Yantis, Osman, & Smith, 1984, 1985; Ratcliff, 1978). Specifically, these critics have taken issue with the assumption that there is no temporal overlap between the functionally distinct processes that operate on incoming information. In a stage model such as Sternberg’s (1969), each psychological process runs to completion before the next process begins; a process produces output at only one point in time, the point at which it has reached the highest level of accuracy for which it is currently set. There are other models of information processing, however, that assume that functionally
distinct psychological processes can operate simultaneously (e.g., McClelland, 1979). In this type of model, as one psychological process operates on incoming information, it continually makes available the results of its operations to succeeding processes; as a result, these processes can begin even before the earlier process is completed. In such continuous-output models, the output of a psychological process at any given time is of a probabilistic nature, constituting a guess based on the processing completed so far (e.g., the encoding process may make available very rapidly the information that the odds are .5 that the stimulus is a dog and .5 that it is a shadow). As a process operates longer on the information, the output being produced by that process becomes more accurate, finally reaching the highest level of accuracy of which it is currently capable (e.g., the odds are .999 that the stimulus is a dog).

The reader is referred to McClelland (1979) for a more thorough discussion of the limitations of stage models and their relationship to continuous models. For the present purposes, the most important difference between discrete-stage models and continuous-output models concerns the inferences made when two factors have interactive effects on overall response-time accuracy. Under the assumptions of a stage model, if two factors produce an interactive effect on overall response time, they must be affecting the same processing stage. However, within the framework of a continuous model, two factors may affect different psychological processes and yet produce an interactive effect on overall response time, in that the speed and accuracy of one process can affect the speed and accuracy of another process by determining the amount of information available to that process at different points in time.

Continuous and discrete-stage models are in greater agreement about the interpretation of a finding that two factors have additive effects on overall response time. In models of both types, such additivity generally implies that the two factors affect different psychological processes. As will be seen, the most important conclusions of the present studies are based on the finding of additive relationships between factors. Therefore, the most significant of the conclusions drawn here would hold equally well under the assumptions of stage and continuous models of information processing.

Signal-Detection Measures

In analyzing the findings of the present studies, we have also used two measures drawn from signal-detection theory (Green & Swets, 1966). One of these measures, d-prime, is a pure index of perceptual sensitivity. The other measure, beta, is a pure index of response bias. According to a simple speed-accuracy tradeoff model of impulsive cognitive functioning, high-impulsive individuals are especially inaccurate because they do not spend enough time processing the relevant information before responding. Such inadequate processing would be reflected in a reduced d-prime. It is conceivable, however, that the inaccuracy of impulsive individuals is not due to their inadequate processing but to a strong a priori preference for responding in certain ways (e.g., a bias to say "yes" in response to a yes—no question or a bias to say "same" when asked if two objects are the same or different). It would be of value to determine whether such a response bias accounts for any accuracy differences observed between high impulsives and other individuals. A failure to find that individual differences in impulsivity are associated with differences in beta would eliminate this possibility.

Overview of Experiments

The present article reports three experiments designed to investigate the relationship between impulsivity and information processing. The experimental task used in all three of these experiments was a visual-comparison task. Subjects had to judge whether pairs of complex geometric figures were the same or different. The effects of impulsivity and other factors on the speed and accuracy of performance were measured and analyzed in terms of additive-factor logic.

We chose to use a visual-comparison task for several reasons. First, deciding whether two visual stimuli are the same or different is an extremely basic process that provides a foundation for many other higher level cognitive activities. Second, we have found an association between impulsivity and the way decisions are made about complex visual stimuli in some of our past research (Dickman, 1985). Third, some previous investigators, using a task similar to the present one, have suggested that there may be systematic individual differences in the way people go about making some—different judgments of the sort involved in this task (Cooper, 1976; Cooper & Podgorny, 1976). Fourth, the use of a visual-comparison task linked our work to previous research on reflection—impulsivity (e.g., Kagan, 1966), inasmuch as the MFFT also involves comparing complex figures.

Briefly, the aim of Experiment 1 was to determine whether, over a range of experimental conditions varying in the payoff for speed relative to accuracy, subjects identified as high in impulsivity by means of a self-report measure would consistently respond more quickly and less accurately than other individuals. This was found to be the case. In addition, there was some evidence that the speed—accuracy tradeoff curves of the high-impulsive subjects differed from those of the medium and low impulsives. However, the data also suggested that high-impulsive subjects do not carry out all processing stages especially rapidly and inaccurately. The data were consistent with the conclusion that high impulsives were using a different information-processing strategy than the other two groups.

The purpose of Experiment 2 was to explore further the factors leading to the relative inaccuracy of high-impulsive subjects in Experiment 1. High-, medium-, and low-impulsive subjects were required to perform an information-processing task at the same speed to see whether accuracy differences would persist under these conditions. We found that impulsivity-related accuracy differences were in fact present under these conditions. Under most conditions, high-impulsive subjects were less accurate than other subjects. However, at the fastest processing speeds, high impulsives actually performed more accurately than did low-impulsive subjects. This is again consistent with the view that high impulsives were using a qualitatively different strategy from that used by other subjects, a strategy that was under some circumstances more error prone than the strategies of other subjects but under other circumstances less error prone.
Finally, the aim of Experiment 3 was to explore further the cross-stage consistency of the processing differences found between high, medium, and low impulsives in the previous two experiments. In particular, we sought to identify the specific stage of processing that, in Experiment 1, was carried out no faster or less accurately by high impulsives than by other individuals. We identified the stage of response execution as one that the three impulsivity groups carried out with identical speed and accuracy. In addition, we found that low and medium impulsives did not differ in their speed and accuracy at the feature-comparison stage, although high impulsives did differ from the other two groups at this stage. Thus, these findings make clear the limitations of a simple speed-accuracy tradeoff model of impulsive cognitive functioning. A model that assumes only that high impulsives carry out all aspects of information processing faster and less accurately than low impulsives is inadequate to account for these data.

Experiment 1
Method

Subjects

All subjects were undergraduate students. They were selected from a larger pool of 60 individuals on the basis of their scores on a self-report measure of impulsivity (Craig, Humphreys, Rocklin, & Revelle, 1979). This questionnaire also included buffer items drawn from a measure of social desirability (Crowne & Marlowe, 1960) and a measure of venturesomeness (Eysenck & Eysenck, 1978).

From the initial group of 60 individuals, three subgroups of subjects were selected for further study. These subjects represented the top, middle, and bottom 20% of the distribution of impulsivity scores. There were originally 12 subjects in each group, for a total of 36 subjects.

However, 3 subjects had to be discarded, 1 because of failure to follow instructions, 1 because of vision problems, and 1 because of scheduling difficulties that could not be resolved. All 3 of the discarded subjects belonged to the medium-impulsive group, leaving 9 subjects in that group and 12 in each of the other two groups. The final 33 subjects who participated in this experiment included 14 men and 19 women.

Stimulus Materials

As previously noted, the experimental task required subjects to compare two complex geometric figures and indicate whether the outlines of those figures were identical. The figures were ones previously used in research on visual-comparison processes (Cooper, 1976; Cooper & Podgorny, 1976). Cooper created these figures by generating an array of points and then connecting these points with lines. Some examples of these figures appear in Figure 3.

Thirty of Cooper’s figures were used in this experiment. We paired each of these figures with itself to create 30 same pairs. Fifteen different pairs were created by pairing figures whose outlines differed only in the placement of a single dot. Fifteen additional different pairs were created by taking the 15 original different pairs and reversing the order of the figures. There were thus a total of 30 same and 30 different pairs.

We created the pairs in this fashion to ensure that the visual-comparison task was relatively difficult. This reduced the possibility that floor effects would complicate the interpretation of the accuracy data. The experimental task thus had a considerable degree of “response uncertainty,” in Kagan’s (1966) terms.

The figure pairs were reproduced on 11-inch by 14-inch sheets of
Paper, using a high-quality photocopier. Each stimulus sheet contained
56 figure pairs, representing a random selection of 28 of the 30 same
pairs and 28 of the 30 different pairs. There were 14 rows of 4 figure
pairs each. Same and different pairs were randomly intermixed. To the
right of each figure pair were the letters S and D, one above the other.
Eight different stimulus sheets were created in this way. Three of the
sheets were used for practice trials, and five for test trials.

Procedure

Subjects received $4 per hour for their participation, plus a bonus
based on good performance. They were run individually in sessions last-
ing approximately 45 min.

Each experimental trial lasted 90 s. During a trial, the subject's task
was to compare the pairs of figures on a single stimulus sheet, crossing
out the S to the right of each pair of figures that were the same, and
crossing out the D to the right of each pair of figures that were different.
Subjects were instructed to work from left to right across each row, with-
out skipping any figure pairs and without going back. They were told
not to correct mistakes, even if they noticed them immediately after-
ward. The experimenter observed the subjects and timed them with a
stopwatch, telling them when to start and when to stop.

Experimental conditions. We used five payoff conditions that differed
in terms of the monetary reward given for rapid performance relative
to the monetary reward for accurate performance. Each trial was associ-
ated with a specific payoff condition, and the payoff conditions varied
across trials. As noted above, the reason for varying the payoff condi-
tions was to determine whether impulsivity-related differences in speed
and accuracy would emerge under all circumstances or only when the
situation itself did not strongly demand either speed or accuracy.

Subjects were told that they could earn points on each trial and that,
at the end of the experiment, the 12 subjects with the most points would
receive a monetary bonus. On all trials, subjects received 10 points for
each correct response that they made. The number of points lost for
each error depended on the condition; this penalty was either 2, 5, 10,
20, or 50 points. Thus, the −2 condition was the one in which speed
had the greatest value, and the −50 condition was the one in which
accuracy had the greatest value.

Subjects were informed about the current payoff condition (i.e., the
points to be lost for each error) before each trial. In addition, all payoff
conditions were listed on a blackboard in front of the subject, and an
arrow was drawn next to the current condition.

Supplementary stimulus sheets. Pilot work had indicated that sub-
jects were rarely able to complete an entire stimulus sheet within 90 s.
However, all subjects were told that if they did happen to finish a stimu-
lus sheet before 90 s elapsed, they should take a supplementary sheet
from a pile next to them and keep on going. Each supplementary sheet
consisted of 28 figure pairs, half same and half different.

The data from the supplementary sheets were ignored because sub-
jects took varying amounts of time to switch to the new stimulus sheets,
and this would have represented an unwanted source of noise in the
data. Therefore, on those infrequent trials where a subject finished the
initial stimulus sheet before 90 s had elapsed, the subject's speed and
accuracy for this initial sheet were used to estimate how many correct
and incorrect comparisons the subject would have made in 90 s; these
values were then used to determine how many points the subject was
awarded for the trial.

Practice trials. The first four trials in the experiment were practice
trials. On the first practice trial, the subject worked on a stimulus sheet
containing 28 figure pairs (half same and half different). The subject was
told to complete the sheet, taking as much time as he or she wanted. No
points were awarded for this trial. Its purpose was simply to ensure that
the subjects all understood the task. When the subject had completed
this practice sheet, the experimenter scored it and provided feedback to
the subject about his or her performance. This was the only trial on
which such feedback was given.

On the next three practice trials, subjects could earn points. The pay-
off conditions here were −2, −10, and −50. These practice trials were
intended to expose subjects to the range of payoff conditions used in the
test trials.

Test trials. After the practice trials were completed, subjects went
through three blocks of test trials. Each block included five payoff
conditions. The conditions were always presented in one of two orders,
either from −2 to −50 or from −50 to −2. The orderliness of the condi-
tions made it easier for subjects to keep in mind which condition they
were in and therefore what strategy they wanted to use.

Within the high- and low-impulsivity groups, half of the subjects
started with the −2 condition, and the other half started with the −50
condition; the proportion was 5:4 in the medium-impulsive group. The
order was reversed from the first test block to the second and from the
second to the third. The order of the five different stimulus sheets was
also counterbalanced within each impulsivity group; this order was the
same for the three blocks.

Data analyses. The data were averaged over blocks before the main
analyses were performed. Preliminary analyses, involving block as a
factor, indicated that subjects' performance improved across blocks
(they became faster and more accurate) but that no significant interac-
tions occurred between block and any other factor.

Results

Separate analyses of variance were performed for time per item (TPI) and percent correct (PC). The TPI was calculated by
dividing the number of pairs completed in a block by 90 s, the
total time allowed for the block.

In both analyses, the factors were impulsivity (low, medium,
high) and payoff condition (−2, −5, −10, −20, −50). The mean
TPIs and PCs for the three impulsivity groups in these different
payoff conditions are presented in Figures 4 and 5.

TPI and Percent Correct

There were significant main effects of payoff condition in both analyses. The TPI increased significantly from the −2 to
the −50 condition, F(4, 120) = 30.53, p < .001, as did accuracy,
F(4, 120) = 10.93, p < .001. All subjects, then, were sensitive
to the payoff differences between conditions.

Both analyses also revealed a significant main effect of impuls-
ivity. High impulsives had the lowest average TPI, and low
impulsives had the highest, with medium impulsives falling in be-
between, F(2, 30) = 4.50, p < .05. High impulsives were the least
accurate, and low impulsives were the most accurate, with me-
dium impulsives again being intermediate, F(2, 30) = 4.58, p < .05. These findings provide direct evidence for an association
between the personality trait of impulsivity and a bias toward fast,
inaccurate information processing.

The interaction between impulsivity and payoff condition
was not significant in the analyses of either TPI, F(8, 120) = 0.88,
or PC, F(8, 120) = 1.41. Thus, individual differences in
impulsivity were related to performance differences across a
range of conditions, and they manifested themselves even when the
payoff contingencies strongly emphasized speed or accu-

As was noted earlier, it is possible to apply the logic of Sternberg’s (1969) additive-factor method directly to raw speed data (i.e., TPI), but in order to apply the same logic to accuracy data (i.e., PC), those data must first be logarithmically transformed. Such a transformation was carried out, and the analysis of log PC produced findings essentially identical to those from the analysis of raw PC. The main effects of both payoff condition, $F(4, 120) = 10.23, p < .0001$, and impulsivity, $F(2, 30) = 4.64, p < .05$, were significant, but the interaction between these two factors was not, $F(8, 120) = 1.67$. The implications of these findings will be discussed below.

**d-Prime and Beta**

Additional analyses of variance were performed on the signal-detection measures, d-prime and beta. As was noted, d-prime is a pure measure of perceptual sensitivity, whereas beta is a pure measure of response bias.

The analysis of variance for d-prime yielded findings very similar to those for PC and log PC. There was a significant main effect of payoff condition, $F(4, 120) = 4.27, p < .01$; all subjects showed greater perceptual sensitivity in those conditions in which the cost of errors was greatest. The main effect of impulsivity approached significance, $F(2, 30) = 2.26, p = .12$, with high impulsives showing less perceptual sensitivity than did low impulsives. The interaction between impulsivity and payoff condition was far from significant, $F(8, 120) = 0.56, p = .81$. For beta, there was a significant main effect of payoff condition, $F(4, 120) = 4.85, p < .01$. All subjects showed a bias toward responding *same*, and this bias was more pronounced in the payoff conditions that emphasized speed than in the ones that emphasized accuracy. However, neither the main effect of impulsivity, $F(2, 30) = 2.76$, nor the interaction between impulsivity and payoff condition, $F(8, 120) = 0.56$, was significant. Thus, the rapid responding of impulsive individuals is not reflected in a greater bias toward making either *same* or *different* responses but rather in a generally reduced level of perceptual sensitivity, an increase in both false *same* and false *different* responses.

**Points Gained**

The number of points gained by subjects under each payoff condition was also submitted to an analysis of variance. This variable is a direct index of how well the subject was able to adjust his or her speed and accuracy in response to the demands (i.e., payoff contingencies) in each experimental condition. The factors in this analysis were impulsivity and payoff condition. The mean number of points gained by each impulsivity group in each payoff condition appear in Figure 6.

There was a significant main effect of payoff condition, $F(4, 120) = 76.08, p < .0001$, on the number of points gained. Subjects earned more points in the payoff conditions that emphasized speed (e.g., $-2$) than in the conditions that emphasized accuracy (e.g., $-50$). The main effect of impulsivity was not significant, $F(2, 30) = 1.56$, but there was a significant interaction between impulsivity and payoff condition, $F(8, 120) = 2.21, p < .05$. Post hoc comparisons, using the Duncan multiple-range test, clarified these findings. In the $-50$ condition, medium impulsives gained more points than high impulsives, $q(3,
Figure 5. Mean percent correct as a function of payoff condition and impulsivity level in Experiment 1.

Figure 6. Mean points earned as a function of payoff condition and impulsivity level in Experiment 1.
impulsives. The superiority of both medium impulsives, \( q(3, 120) = 4.17, p < .01 \), and high impulsives, \( q(2, 120) = 3.41, p < .05 \), over low impulsives also held for the \(-5\) condition. Medium impulsives and high impulsives did not differ in either the \(-2\), \( q(2, 120) = 0.28, \) or the \(-5\), \( q(2, 120) = 0.76, \) condition.

**Discussion**

The data from Experiment 1 demonstrate that individual differences in impulsivity are associated with individual differences in the speed and accuracy of cognitive functioning. However, these data also indicate that a simple speed–accuracy tradeoff model of impulsive cognitive functioning is inadequate. High-impulsive subjects did not carry out every stage of information processing more rapidly (and hence less accurately) than other subjects did.

This latter conclusion is based on the application of Sternberg's (1969) additive-factor method. The significant main effects of both impulsivity and payoff condition in the analyses of TPI and log PC indicate that each of these factors influenced the speed and accuracy of at least one processing stage. The lack of a significant interaction between the two factors indicates that there was at least one processing stage whose speed and accuracy could be altered (i.e., in response to payoff conditions) but which was carried out no faster or less accurately by high-impulsive subjects than by other subjects.

Thus, both the penalty for making errors and the personality trait of impulsivity affect the speed and accuracy of information processing. However, they do so in different ways, that is, by influencing different processing stages.

**Impulsivity and Optimality of Performance**

The data on points earned by subjects suggest that individuals at both extremes of the impulsivity continuum are at a disadvantage under certain circumstances. In this experiment, high impulsives were at a disadvantage when accuracy was rewarded much more than speed (e.g., the \(-50\) condition), whereas low impulsives were at a disadvantage when speed was rewarded much more than accuracy (e.g., the \(-2\) condition).

Medium impulsives consistently gained as many points as the better of the other two groups. The superior performance of medium impulsives was likewise evident in the raw speed and accuracy data. As Figures 4 and 5 indicate, when the payoff conditions emphasized speed, medium impulsives were similar to high impulsives in both speed and accuracy. In contrast, when the payoff conditions emphasized accuracy, medium impulsives resembled low impulsives in both their speed and accuracy. Thus, it appears that individuals in the middle of the impulsivity continuum, because they have no strong predisposition to adopt either speed-oriented or accuracy-oriented strategies, are more likely than other individuals to adopt the strategy that is optimal under the prevailing circumstances.

**Speed–Accuracy Tradeoff Curves**

The speed–accuracy tradeoff curves generated by subjects in the three impulsivity groups are shown in Figure 7. These curves are based on each impulsivity group's average level of accuracy at five different speeds; these were the average speeds for that impulsivity group in each of the five payoff conditions. Unfortunately, any conclusions drawn from these curves must be considered tentative because the three groups used different ranges of speeds, and such factors as floor and ceiling effects are likely to have an impact on speed–accuracy tradeoffs.

The data presented in Figure 7 do suggest that the speed–accuracy tradeoff curves for low and medium impulsives are very similar. Thus, these two groups of subjects seem to be equally error prone at a given speed. However, it appears that the speed–accuracy tradeoff curve for high impulsives is different from those of the other two subject groups. High impulsives seem to be more error prone than the other groups at a given speed.

Two factors could account for the difference between the speed–accuracy tradeoff curve of high impulsives and the curves of the other two groups. One is that high impulsives are less intelligent or in some other way less able than the other two groups. The other is that high impulsives use a qualitatively different strategy from the other two groups, a strategy that is inherently more error prone. The latter explanation seems more plausible, because if impulsivity and ability were correlated, one would expect low and medium impulsives to differ as well, with medium impulsives being at least slightly more error prone at the same speed than low impulsives.

Thus, Experiment 1 at least raises the possibility that the error proneness of high impulsives is due not only to their preference for rapid information processing but to other factors as well. Experiment 2 was undertaken to explore further the sources of high impulsives' inaccurate performance.

**Experiment 2**

In Experiment 2, subjects performed the same visual-comparison task as in Experiment 1. However, in this experiment,
all subjects were required to spend the same amount of time on each of the figure comparisons.

If the lesser accuracy of high impulsive subjects was due solely to their greater processing speed, as a simple speed-accuracy tradeoff model of impulsive cognitive functioning would hold, accuracy differences would be expected to disappear if high, medium, and low impulsive subjects were made to perform a task at the same speed.

If accuracy differences did persist in the absence of speed differences, the critical question would be whether those accuracy differences were due to ability differences or to strategy differences. If high impulsive subjects continued to be less accurate than other subjects at all processing speeds, even when other subjects were forced to respond at the very rapid rate that high impulsive subjects prefer, it would suggest that ability differences account in part for the relative inaccuracy of high impulsive subjects. If, on the other hand, high impulsive subjects showed equal or superior performance when all subjects were forced to process information very rapidly, it would suggest that the relatively inaccurate performance of these subjects at slower speeds is due to the nature of their preferred strategy rather than to a lack of ability.

**Method**

**Subjects**

The subjects were the same as in Experiment 1.

**Materials**

The same figure pairs as before were used. The pairs included six different sets, with 36 pairs per set. Each set was drawn randomly from the 30 same and 30 different pairs generated for Experiment 1. There were equal numbers of same and different pairs in each set.

**Procedure**

Subjects again participated individually. As before, they received $4 per hour, plus a bonus for good performance. The experiment lasted about 45 min.

As in Experiment 1, subjects made same-different judgments about pairs of geometric figures. Subjects responded orally to each pair. They said "S" if the figures were the same and "D" if they were different. The experimenter recorded the responses.

To control the amount of time subjects took to make each judgment, a memory drum was used to present the figure pairs. The experimental conditions differed only in the amount of time that each figure pair appeared in the window of the drum. Six exposure durations were used: 0.5 s, 1.0 s, 1.5 s, 2.0 s, 3.0 s, and 4.0 s. These exposure durations were chosen on the basis of pilot work that indicated that the shortest durations yielded a considerable number of errors and the longest exposure durations yielded a very low error rate.

To maintain the similarity of the second experiment, the exposure durations were presented in ascending and descending orders, either from 0.5 s to 4.0 s or from 4.0 s to 0.5 s. A block of trials consisted of 216 figure pairs, with 36 figure pairs at each of the six exposure durations. There were two blocks of trials, with the order of the exposure durations reversed from the first block to the second. Half the subjects in each impulsivity group began with the 0.5-s condition, and the other half began with the 4.0-s condition (except for the medium impulsivity group, for whom the proportion was 5:4). The order of the six different sets of figure pairs was counterbalanced within each impulsivity group. The stimulus sets appeared in the same order in the two blocks.

There was one set of practice trials prior to the test trials. A separate stimulus set was used for the practice trials. The exposure duration for it was 2.0 s, in the middle range of exposure durations.

**Instructions.** The instructions were designed to ensure that all subjects spent the same amount of time comparing the figures in a given pair. These instructions stressed that subjects should continue comparing each pair of figures for as long as those figures remained visible in the memory-drum window. To make sure that subjects actually obeyed these instructions, they were allowed to respond only while the memory drum shutter was closed. The shutter was closed for just 0.5 s between figure pairs. Thus, a subject who stopped processing the figures before the allotted time was up and allowed his or her mind to wander would not be prepared to respond as soon as the shutter came down and would probably not be able to respond before the shutter opened again. In the same way, a subject who continued comparing his or her mental image of the figures even after the shutter had closed would not be likely to have enough time to respond before the shutter opened again.

Subjects were told that they would receive 10 points for each correct response and lose 40 points for each error. As in Experiment 1, subjects were told that the 12 subjects with the most points would receive a monetary bonus. Awarding points in this fashion ensured that subjects' level of motivation did not differ between the two experiments.

**Data analyses.** The data were averaged across blocks of trials. Preliminary analyses indicated that although performance improved across blocks (e.g., PC increased), block did not interact significantly with any of the other factors.

**Results**

**Percentage Correct**

An analysis of variance was performed on the percentage of correct responses. The factors were impulsivity (low, medium, and high) and exposure duration (0.5 s, 1.0 s, 1.5 s, 2.0 s, 3.0 s, and 4.0 s). Means for the three impulsivity groups under each exposure duration are presented in Figure 8.
The main effect of exposure duration was significant, \( F(5, 150) = 221.82, p < .0001 \). As expected, accuracy was lower for the shorter exposure durations. The main effect of impulsivity was significant, \( F(2, 30) = 3.60, p < .05 \), with low impulsives being the most accurate overall and high impulsives the least accurate. For the present purposes, the most important finding was a significant interaction between impulsivity and exposure duration, \( F(10, 150) = 4.53, p < .0001 \). Post hoc comparisons, using the Duncan multiple-range test, clarified this finding. High impulsives were significantly less accurate than low impulsives in the 1.0-s condition, \( q(2, 150) = 6.22, p < .01 \); the 1.5-s condition, \( q(2, 150) = 2.72, p < .05 \); the 2.0-s condition, \( q(2, 150) = 4.07, p < .01 \); the 3.0-s condition, \( q(3, 150) = 4.07, p < .01 \); and the 4.0-s condition, \( q(3, 150) = 3.28, p < .01 \). Also, high impulsives were less accurate than medium impulsives in the 1.0-s condition, \( q(3, 150) = 7.81, p < .01 \); the 1.5-s condition, \( q(3, 150) = 4.87, p < .01 \); the 2.0-s condition, \( q(3, 150) = 6.19, p < .01 \); and the 3.0-s condition, \( q(2, 150) = 4.07, p < .01 \). The superiority of medium impulsives over high impulsives approached significance in the 4.0-s condition, \( q(2, 150) = 2.34, p < .07 \). However, in the 0.5-s condition, both high impulsives, \( q(2, 150) = 4.53, p < .01 \), and medium impulsives, \( q(3, 150) = 6.07, p < .01 \), were significantly more accurate than low impulsives; high and medium impulsives did not differ significantly in their level of accuracy at this exposure duration, \( q(2, 150) = 1.55 \).

Log Percentage Correct

As in Experiment 1, an analysis was performed on the accuracy data in the form of log PC; this made it possible to interpret the findings for accuracy in terms of Sternberg's (1969) additive-factor method.

The analysis of log PC yielded essentially the same findings as the analysis of raw PC. The main effect of exposure duration was significant, \( F(5, 150) = 207.57, p < .0001 \); the main effect of impulsivity was barely significant, \( F(2, 30) = 3.40, p = .047 \); and the Impulsivity \times Exposure Duration interaction was significant, \( F(10, 150) = 4.59, p < .0001 \).

\( d' \)-Prime and Beta

The accuracy data from Experiment 2 were also analyzed in terms of the signal-detection measures, \( d' \)-prime and beta. For \( d' \)-prime, the results were essentially the same as for PC. There was a significant main effect of exposure duration, \( F(5, 150) = 124.94, p < .0001 \), and a significant interaction between impulsivity and exposure duration, \( F(10, 150) = 2.48, p < .01 \). The main effect of impulsivity was marginally significant, \( F(2, 30) = 3.16, p = .057 \).

For beta, the main effect of exposure duration was significant, \( F(5, 150) = 16.71, p < .0001 \). Subjects had a general tendency to err in the direction of saying that the figures were the same, and this tendency was more pronounced for the shorter exposure durations. However, neither the main effect of impulsivity, \( F(2, 30) = 0.47 \), nor the interaction between impulsivity and exposure duration, \( F(10, 150) = 1.41 \), was significant.

The signal-detection analyses clarify the nature of the relationship between impulsivity and response accuracy. Individual differences in impulsivity were associated with differences in subjects' perceptual sensitivity to discrepancies between the two figures but were not associated with differences in response bias (i.e., in the tendency to err in the direction of making incorrect same or incorrect different responses). This pattern of findings is similar to the findings for the signal-detection measures in Experiment 1.

**Points Gained**

No analysis was performed on the number of points that subjects gained in each exposure condition. The number of points gained was entirely a function of subjects' accuracy, under the conditions of this experiment. An analysis of the point data would therefore not have yielded any information beyond that provided by the analyses of the accuracy data.

**Discussion**

The findings of Experiment 2, like those of Experiment 1, are difficult to reconcile with a simple speed-accuracy tradeoff model of impulsive cognitive functioning. The impulsivity groups differed in accuracy even when processing-time differences had been eliminated.

The data from this experiment, like the speed-accuracy tradeoff curves generated by subjects in the first experiment, suggest that the relative inaccuracy of high impulsives in Experiment 1 was due to their use of a qualitatively different strategy from that of the other subjects rather than to a lack of ability on their part.

It is the 0.5-s condition of the present experiment that provides the most direct evidence for such strategy differences. In this condition, high impulsives actually performed more accurately than low impulsives, a fact that is difficult to reconcile with the view that high impulsives are lower in some perceptual or cognitive ability than are other subjects.

Thus, it appears that when high impulsives make same-different judgments, they use a strategy that produces especially rapid responses but that is intrinsically error prone. Under most conditions, such a strategy yields a relatively high number of errors even when high impulsives spend as much time on the same-different judgment as do other subjects.

One stage of information processing at which such impulsivity-related strategy differences may occur is the feature-comparison stage. Same-different judgments, like those required by the present task, presumably involve comparing homologous (i.e., corresponding) features of the two figures in order to determine whether these features are identical. Cooper (1976; Cooper & Podgorny, 1976) has obtained data that suggest that subjects differ in terms of the strategies they use to carry out these feature comparisons. Strategy differences of the sort that Cooper has identified could well account for the impulsivity-related differences in performance found in this study.

For example, high impulsives may adopt the strategy of making all of the comparisons of pairs of homologous features at the same time (i.e., in parallel), whereas low impulsives adopt the strategy of comparing one pair of homologous features at a
time in a slow, thorough, serial fashion. High impulsives would prefer a wholistic strategy because making all of the necessary comparisons at once would result in especially rapid responses. Low impulsives would prefer a sequential strategy because this would allow them to devote all of their processing resources to each one of the feature comparisons instead of having to divide up those resources among a number of simultaneously occurring comparisons; such a strategy would be likely to produce especially accurate responses.

The advantage in accuracy associated with a sequential comparison strategy may well be reduced, and even reversed, at very brief exposure durations (i.e., 0.5 sec). When the time available for the comparison of pairs of homologous features is extremely limited, subjects who carry out these comparisons slowly and one at a time may fail to complete all of the comparisons within the time available. Unless one of the completed feature comparisons happens by chance to indicate that the two figures differ, low impulsives would simply have to guess about the overall same–different judgment. This could easily reduce the accuracy of their judgments below that of high impulsives, who would have made all of the comparisons at once and would therefore have extracted at least some useful information about every homologous pair of features, despite the brevity of the exposure of the figures.

It therefore seems possible to account for the present findings without abandoning a speed–accuracy tradeoff model of impulsivity–related differences in cognitive functioning. It is necessary, however, to elaborate on the basic model. The value placed on speed relative to accuracy in information processing must be assumed to influence not only the speed with which a subject processes information but also the type of strategy that the subject uses in this processing. The choice of strategy is not necessarily determined by its potential accuracy at the level of analysis that an experimenter chooses to use. Low impulsives may prefer to be accurate at each stage in the information-processing sequence, even though this lowers the accuracy of the final response owing to a failure to complete all of the steps in that sequence in the time allotted.

Other Evidence of Strategy Differences

The analysis of log PC in Experiment 2 was consistent with the explanation just offered for the raw accuracy data. It was suggested that both impulsivity and exposure duration influence the stage of information processing at which homologous features are compared, with impulsivity affecting the strategy used to carry out those comparisons and exposure duration determining the amount of time available for those comparisons. If these two factors influence at least one stage of processing in common, the ought to show a significant interaction, according to the logic of Sternberg’s (1969) additive-factor method. The log PC analysis showed such an interaction.

Medium Impulsives

It is also worth noting that at all exposure durations, medium impulsives performed as well as the better of the other two groups. The superior performance of medium impulsives in Ex-periments 1 and 2 suggests that their position in the middle of the impulsivity continuum, their lack of a strong preference for either speed or accuracy, increases the likelihood that these individuals will adopt the strategy that best meets the demands of the situation. Their lack of an a priori bias renders them especially flexible.

Experiment 3

Experiments 1 and 2 demonstrate that individual differences in impulsivity are associated with differences in the speed and accuracy of information processing. However, Experiment 1 also revealed that there is at least one stage of information processing that the three impulsivity groups carried out with identical speed and accuracy; this was the stage whose speed and accuracy subjects altered in response to payoff conditions. The aim of Experiment 3 was to explore this finding further. In this experiment, we sought to compare the performance of the three impulsivity groups at specific stages of processing in order to see which stage or stages the three groups carry out identically.

Experiment 3 examined two stages of processing in particular. These stages were ones that seemed especially likely to have been altered by subjects in Experiment 1 in response to payoff conditions. One of these stages was the response-execution stage. This is the stage at which the subject prepares and executes the motor response that is his or her overt response to the stimulus input. Errors can occur at this stage if the subject issues the wrong set of motor commands to produce the intended response, or if the subject fails to accurately monitor the response as it is being executed to ensure that it is being executed properly (Schmidt, 1976).

Another stage that could have been altered in response to shifting payoff contingencies in Experiment 1 is the featurecomparison stage. It seems plausible that subjects would be able to increase or decrease the speed and accuracy with which they compare two figures. Although the data from Experiment 2 provided some evidence that there are impulsivity-related differences at this stage, it seemed worthwhile to obtain additional evidence in this regard.

Experiment 3 included experimental manipulations designed to selectively influence both the response-execution and the feature-comparison stages. Under both discrete-stage and continuous models of information processing, if a factor that influences a particular stage (or mental process) does not interact significantly with impulsivity in its effects on overall response-time accuracy, it can be inferred that impulsivity-related differences are not present at that stage.

Method

Subjects

The subjects were again undergraduates and were selected on the basis of their scores on the same impulsivity scale used in the previous two studies. From an initial pool of 70 individuals, those individuals in the upper, middle, and lower 20% of the range of impulsivity scores were selected for further study.
Stimulus Materials

The presentation of the figure pairs and recording of the responses was controlled by a microcomputer. The figure pairs were presented in the center of the computer display screen. Subjects responded by pressing the appropriate key on the keyboard.

The stimuli used in the visual-comparison task in this experiment were geometric figures made up of Xs. Each figure was created by removing one or more Xs from an array that was 5 Xs high and 10 Xs wide. To enhance the goodness of these figures, the array was compressed vertically. Therefore, adjacent Xs touched each other, both horizontally and vertically. Figures of this sort were used for two reasons: (a) Because they were made up of distinct units, it was possible to specify the differences between figures in a more precise fashion than is possible with the type of geometric figures used in the previous experiments; and (b) it seemed worthwhile to obtain some indication of the generality of the findings of the two earlier studies across different types of figures.

Response Complexity

In order to manipulate the speed and accuracy of the response-execution stage, Experiment 3 included two conditions that differed only in the complexity of the required response. In the simple response condition, a blue dot was placed over one key and a red dot over another (the actual keys were 1/1 and +/=); subjects simply had to press the key corresponding to the correct response. In the complex response condition, subjects again had to press the red or blue key to indicate a same or different response; however, in this condition, they were required to simultaneously press the Shift key on the opposite side of the keyboard from the response key they were pressing.

In both the simple and the complex response conditions, the association between key and response (i.e., same, different) was counterbalanced within impulsivity groups. Between trials, subjects were required to keep their index fingers resting on the red and blue keys.

Figural Complexity

In order to manipulate the speed and accuracy of the feature-comparison stage, two different sets of figure pairs were generated. These figure pairs differed in the complexity of the figures. The figures were created by removing Xs at random from the periphery of the array of Xs described earlier. For the simple figures, 8 Xs were removed at random until the figure contained 18 to 22 corners. For the complex figures, 17 Xs were randomly removed until the figure contained 38 to 42 corners (see Figure 9 for examples of a simple and a complex figure pair).

Each figure created in this way was paired with itself to form a same figure pair. For different pairs, one of the figures in the same pair was altered by changing the position of a single X in the periphery of the figure. Eight sets of 12 simple pairs and eight sets of 12 complex pairs were created in this fashion; two sets of each type were used for practice.

Procedure

Subjects were tested in sessions that lasted approximately 1 hour. As in the previous experiments, subjects were informed that they would receive a bonus for good performance.

There were four practice sets of figures, followed by 12 test sets. The nature of the figure pairs (simple vs. complex) and the nature of the response (simple vs. complex) remained constant within each set of figure pairs. The practice sets consisted of two sets of simple figures, one requiring the simple response and one the complex response, and two sets of complex figures, one requiring the simple response and one the complex response. For the 12 test sets, half of the sets of simple figures required the simple response, and half required the complex response. The same was true for the sets of complex figures. The order of the 12 sets was counterbalanced separately within each impulsivity group.

Subjects were informed about the nature of the figures and the required response before each set of figures was presented. On each trial, a fixation point appeared in the center of the screen for 750 ms. The figure pairs were then displayed, also in the center of the screen, and they remained there until the subject responded. The intertrial interval was 1,250 ms. Subjects rested for a minute between sets of figures.

Results

TPI and PC

Analyses of variance were performed for both TPI and PC. In both analyses, there were four factors: impulsivity (low, medium, and high); figure complexity (simple and complex); response complexity (simple and complex); and pair type (same and different). All analyses of PC were based on same–different errors. Occasionally, in the complex response condition, a subject pressed the correct response key but failed to press the Shift key at the same time; however, such errors were infrequent, averaging less than 4% for all three impulsivity groups.

The mean TPIs and PCs for the three impulsivity groups are presented in Table 1. The analyses of both TPI and PC confirmed that the experimental manipulations were successful. The main effect of figure complexity was significant for both TPI, F(1, 39) = 438.34, p < .001, and PC, F(1, 39) = 23.81, p < .001. Subjects in all three impulsivity groups were faster and more accurate when the figures were simple than when they were complex.

The main effect of response complexity was also significant for both TPI, F(1, 39) = 38.05, p < .001, and PC, F(1, 39) = 4.17, p < .05. Subjects in all three impulsivity groups were slower and more accurate when the response was complex than when it was simple.

The interaction between figure complexity and response complexity was not significant for either TPI, F(1, 39) = 1.02,
Table 1
Mean Time Per Item and Percentage Correct for the Three Impulsivity Groups as a Function of Figure Complexity, Response Complexity, and Same Versus Different Pairs

<table>
<thead>
<tr>
<th>Impulsivity group</th>
<th>Figure complexity</th>
<th>Simple</th>
<th></th>
<th>Complex</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Time per item</td>
<td>Percent correct</td>
<td>Time per item</td>
<td>Percent correct</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Same</td>
<td>Different</td>
<td>Same</td>
<td>Different</td>
</tr>
<tr>
<td>Low-impulsive subjects</td>
<td>Simple</td>
<td>444</td>
<td>307</td>
<td>98</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>595</td>
<td>403</td>
<td>97</td>
<td>81</td>
</tr>
<tr>
<td>Medium-impulsive subjects</td>
<td>Simple</td>
<td>427</td>
<td>304</td>
<td>99</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>594</td>
<td>401</td>
<td>99</td>
<td>78</td>
</tr>
<tr>
<td>High-impulsive subjects</td>
<td>Simple</td>
<td>371</td>
<td>262</td>
<td>97</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>483</td>
<td>338</td>
<td>98</td>
<td>76</td>
</tr>
</tbody>
</table>

or PC, F(1, 39) = 2.54. This provides evidence that these two experimental manipulations did in fact affect different stages or processes.

**Pair Type**

The main effect of pair type (i.e., *same* vs. *different* pairs) was significant for both TPI, F(1, 39) = 225.48, p < .001, and PC, F(1, 39) = 157.12, p < .001. Subjects in all three impulsivity groups responded more quickly and less accurately to the *different* pairs.

There was a significant interaction between pair type and figure complexity for both TPI, F(1, 39) = 66.11, p < .001, and PC, F(1, 39) = 27.39, p < .001. Subjects were slower and less accurate with complex figure pairs than with simple pairs; the difference in speed was greatest for *same* pairs, whereas the difference in accuracy was greatest for *different* pairs.

**Impulsivity**

Impulsivity had a significant main effect on TPI, F(2, 39) = 7.55, p < .01; high impulsives were the fastest of the three impulsivity groups, and low impulsives were the slowest.

For PC, the main effect of impulsivity was not significant, F(2, 39) = 0.84. However, the mean PCs were in the expected direction, with high impulsives being the least accurate and low impulsives the most accurate of the three groups.

The critical findings, in terms of testing the experimental hypotheses, concerned the interactions between impulsivity and the other factors. For response complexity, the interaction with impulsivity was not significant for either TPI, F(2, 39) = 0.91, or PC, F(2, 39) = 0.42. Similarly, impulsivity and pair type did not show a significant interaction for either TPI, F(2, 39) = 1.66, or PC, F(2, 39) = 0.82.

Figure complexity and impulsivity did interact significantly for TPI, F(2, 39) = 4.86, p < .05. The Bonferroni t procedure (Kirk, 1982) was used to carry out nonorthogonal contrasts on the TPI means of the three impulsivity groups. Although all three impulsivity groups showed longer TPIs for the complex figures, the difference in TPI between the simple and complex figures was significantly less for the high impulsives than for either the low impulsives, t(9, 39) = 2.77, p < .05, or the medium impulsives, t(9, 39) = 3.33, p < .05; the low and medium impulsives did not differ in this regard, F(9, 39) = 0.56. The Figure Complexity × Impulsivity × Pair Type interaction was not significant for TPI, F(2, 39) = 1.21.

For PC, the two-way interaction between figure complexity and impulsivity was not significant, F(2, 39) = 1.32. However, there was a significant three-way interaction between impulsivity, figure complexity, and pair type, F(2, 39) = 3.21, p < .05. Again, the Bonferroni t procedure was used to carry out nonorthogonal contrasts on the group means. For *same* pairs, the difference between the simple and complex figures was the same for all three groups; high impulsives did not differ from either low impulsives, t(9, 39) = 0.59, or medium impulsives, t(9, 39) = 0.46, and these two groups did not differ from each other, t(9, 39) = 0.13. For *different* pairs, however, the drop in accuracy between the simple and complex pairs was significantly greater for the high impulsives than for the low impulsives, t(9, 39) = 2.85, p < .05; medium impulsives showed a drop in accuracy intermediate between that of the other two groups.

**Log Percentage Correct**

As in Experiments 1 and 2, the accuracy data were analyzed in the form of log PC in order to be able to apply the additive-factor method to the data. The results of this analysis exactly parallel the results of the analysis of raw PC, and only the critical findings will be mentioned here. There were significant main effects of both figure complexity, F(1, 39) = 23.34, p < .01, and response complexity, F(1, 39) = 4.23, p < .05, but the interaction between the two was not significant, F(1, 39) = 2.30. The interaction between impulsivity and response complexity was not significant, F(2, 39) = 0.37. The two-way interaction between figure complexity and impulsivity was not significant, F(2, 39) = 0.99, but the three-way interaction between figure complexity, pair type, and impulsivity approached statistical
Signal-Detection Measures

Analyses of variance were also performed on the signal-detection measures, d-prime and beta. The factors in these analyses were impulsivity, figure complexity, and response complexity.

These analyses showed a significant main effect of figure complexity for both d-prime, F(1, 39) = 12.56, p < .001, and beta, F(1, 39) = 13.69, p < .001; when the figures were more complex, all subjects were less sensitive to differences between the figures and, in addition, had a greater bias to err in the direction of deciding that the two figures were the same. The significant interaction between impulsivity and figure complexity for PC was paralleled by a significant interaction for beta, F(2, 39) = 3.38, p < .05, but not for d-prime, F(2, 39) = 0.18.

The signal-detection analyses involving response complexity provided less clear-cut findings than did the ones involving figure complexity. Although the main effect of response complexity was significant for PC, it was not significant for either d-prime, F(1, 39) = 1.33, or beta, F(1, 39) = 0.10. This suggests that the effects of response complexity on PC were due to a combination of relatively small effects on both d-prime and beta. Paralleling the results for PC, the interaction between impulsivity and response complexity was not significant for either d-prime, F(2, 39) = 1.02, or beta, F(2, 39) = 2.80.

Discussion

The data from Experiment 3 provide direct evidence that individual differences in impulsivity are not associated with differences in the speed and accuracy of response execution. This conclusion is based on the lack of a significant interaction between impulsivity and response complexity for either TPI or log PC; all subjects were slower and more accurate when the response was complex than when it was simple, and the three impulsivity groups did not differ in this regard. It seems likely that the greater accuracy for the complex response condition was due to the fact that the additional time required for response preparation increased the probability that the subject would detect errors made at the earlier stage of response selection, before response execution had begun. A subject may select the wrong response even though he or she has made a correct judgment about the stimulus. For example, when a particular response has been repeated for several trials in a row, an individual may be predisposed to make that response even when it is wrong (Rabbitt, 1968).

It may be noted that the speed and accuracy data for Experiment 3, presented in Table 1, indicate that compared with high and medium impulsives, low impulsives showed a slightly larger reduction in speed from the simple to the complex response condition, accompanied by a slightly smaller reduction in accuracy. These relatively small differences between low impulsives and the other two groups did not produce a significant Impulsivity X Response Complexity interaction for TPI, PC, log PC, or either of the signal-detection measures. Various post hoc analyses also failed to yield significant differences between low impulsives and the other two groups. Thus, although the data from Experiment 3 cannot entirely rule out the possibility that there is a small difference between low impulsives and the other two groups at the response execution stage, which our design was not powerful enough to capture, this does not seem likely.

In contrast to the lack of group differences at the response execution stage, Experiment 3 provides evidence that high impulsives were different from the other two groups at the stage of feature comparison. This inference is based on the significant interaction between impulsivity and figure complexity. Under the assumptions of a discrete-stage model of information processing (e.g., Sternberg, 1969), such an interaction implies that individuals differing in impulsivity carry out the feature-comparison stage differently. Under the assumptions of a continuous model of information processing (e.g., McClelland, 1979), the inference would be that there are impulsivity-related differences in the speed and accuracy of either the feature-comparison process or a closely related process (i.e., one that either provides direct input to or receives direct input from the feature-comparison process).

The post hoc comparisons carried out following the significant overall interaction between impulsivity and figure complexity revealed that there were no differences in the effects of figure complexity on the speed or accuracy of low and medium impulsives but that high impulsives did differ from the other two groups in this regard. Although high impulsives processed the simple figures no more rapidly than did other subjects, they did not slow down as much as other subjects did when processing the complex figures; as a result, they showed a higher error rate for the complex figures. The significant three-way interaction between impulsivity, figure complexity, and pair type for PC and log PC indicates that the higher error rate of high impulsives for the complex figures took the form of a greater bias toward making false same responses (an increase in beta, in signal-detection terms). This contrasts with Experiments 1 and 2, in which high impulsives’ greater error proneness was manifested in a reduction in perceptual sensitivity (d-prime). The difference between Experiment 3 and the other experiments suggests that the nature of the errors associated with high impulsives’ rapid responding may depend on the nature of the stimuli being processed.

General Discussion

The three studies reported here provide evidence bearing on all four issues raised at the beginning of this article. First, these studies provide direct evidence that individual differences in impulsivity are associated with individual differences in the speed and accuracy of information processing. These differences are qualitative as well as quantitative; high impulsives are faster and less accurate in part because they use information-processing strategies that are inherently faster and less accurate than those used by other individuals.

Second, these studies indicate that individual differences in impulsivity show at least some cross-situational consistency; high, medium, and low impulsives differ in their speed and accuracy not only in situations in which there is little external
pressure for speed or accuracy but also in situations in which the external pressure for speed or accuracy is extreme.

Third, the data provided by these studies support the view that impulsivity is a dimension of style rather than ability; neither extreme of this dimension appears to be inherently superior. The relative superiority of high versus low impulsives will depend on the nature of the task itself.

Finally, these studies suggest that in spite of their generally faster response times and higher error rates, high impulsives carry out at least one stage of processing—response execution—just as slowly and accurately as other individuals. It may be that the reason that high impulsives carry out the stage of response execution relatively slowly and accurately is that inaccurate performance at that stage can have consequences other than an erroneous final response. A failure to accurately program the execution of a motor response can result in physical discomfort or even harm, because the motor response will be carried out in a clumsy fashion. These unpleasant consequences can occur even if the response made is the correct one (e.g., the correct response key is pressed). The concern about immediate physical discomfort may well predispose individuals at all points along the impulsivity continuum to carry out response execution in a slow, careful fashion.

Implications for the Modification of Impulsivity

The finding that high impulsives carry out the stage of response execution relatively slowly and accurately has important implications for research on the modification of impulsivity. In this research, usually conducted with children, high-impulsive subjects are generally identified by means of the MFFT, a task in which accuracy is measured in terms of a final discrete response (i.e., indicating which of the figures is identical to a standard). As noted earlier, on the MFFT, high-impulsive subjects are above the median in speed and below the median in accuracy.

After the high impulsives are identified, an attempt is made to reduce their impulsivity by reinforcing them for slowing down their responses on tasks similar to the MFFT. After this impulsivity-modification procedure has been completed, the impulsive subjects are retested with an alternate form of the MFFT, and their speed and accuracy are compared with those of a control group of impulsives who did not receive the treatment (e.g., Cole & Hartley, 1978; Denney, 1970; Heider, 1971; Kagan, Pearson, & Welch, 1966; Meichenbaum & Goodman, 1971; Nelson & Birkimer, 1978; Ridberg, Parke, & Hetherington, 1971; Zeiniker, Jeffrey, Ault, & Parsons, 1972).

A common finding in this literature is that the treatment designed to reduce impulsivity is successful in slowing down the responses of the impulsive subjects, but without significantly affecting their accuracy (e.g., Denney, 1970; Kagan et al., 1966; Meichenbaum & Goodman, 1971). The present data provide a potential explanation for these findings: When a particular treatment fails to modify high impulsives’ MFFT accuracy even though it causes them to slow down, that treatment might have failed to alter the subjects’ impulsivity at all. That is, the treatment might have failed to alter those aspects of information processing that are habitually carried out more quickly and less accurately by impulsive individuals. Instead, when they are exposed to a treatment designed to make them respond more slowly, high impulsives may take the path of least resistance; they may attempt to reduce the speed of a process, such as response execution, that they are not predisposed to carry out particularly rapidly. The problem with such a strategy is that if high impulsives are already carrying out this process relatively slowly and accurately, ceiling effects may limit the possible improvement in accuracy associated with a reduction in speed. The present findings therefore suggest that the most effective way to train impulsives to be both slower and more accurate may be to explicitly modify components of processing that these individuals habitually carry out faster and less accurately than other individuals.

References


McClelland, J. (1979). On the time relations of mental processes: An


Instructions to Authors

Authors should prepare manuscripts according to the Publication Manual of the American Psychological Association (3rd ed.). Articles not prepared according to the guidelines of the Manual will not be reviewed. All manuscripts must include an abstract of 100–150 words typed on a separate sheet of paper. Typing instructions (all copy must be double-spaced) and instructions on preparing tables, figures, references, metrics, and abstracts appear in the Manual. Also, all manuscripts are subject to editing for sexist language.

APA policy prohibits an author from submitting the same manuscript for concurrent consideration by two or more journals. APA policy also prohibits duplicate publication, that is, publication of a manuscript that has already been published in whole or in substantial part in another journal. Prior and duplicate publication constitutes unethical behavior, and authors have an obligation to consult journal editors if there is any chance or question that the paper might not be suitable for publication in an APA journal. Also, authors of manuscripts submitted to APA journals are expected to have available their raw data throughout the editorial review process and for at least 5 years after the date of publication. For further information on content, authors should refer to the editorial in the March 1979 issue of this journal (Vol. 37, No. 3, pp. 468–469).

The reference citation for any article in any JPSP section follows APA's standard reference style for journal articles; that is, authors, year of publication, article title, journal title, volume number, and page numbers. The citation does not include the section title.

Authors will be required to state in writing that they have complied with APA ethical standards in the treatment of their sample, human or animal, or to describe the details of treatment. A copy of the APA Ethical Principles may be obtained from the APA Ethics Office, 1200 17th Street, N.W., Washington, DC 20036.

Anonymous reviews are optional, and authors who wish anonymous reviews must specifically request them when submitting their manuscripts. Each copy of a manuscript to be anonymously reviewed should include a separate title page with authors' names and affiliations, and these should not appear anywhere else on the manuscript. Footnotes that identify the authors should be typed on a separate page. Authors should make every effort to see that the manuscript itself contains no clues to their identities.

Manuscripts should be submitted in quadruplicate, and all copies should be clear, readable, and on paper of good quality. A dot matrix or unusual typeface is acceptable only if it is clear and legible. Dotted and mimeographed copies will not be considered. Authors should keep a copy of the manuscript to guard against loss. Mail manuscripts to the appropriate section editor. Editors' addresses appear on the inside front cover of the journal.

Section editors reserve the right to redirect papers among themselves as appropriate unless an author specifically requests otherwise. Rejection by one section editor is considered rejection by all, therefore a manuscript rejected by one section editor should not be submitted to another.

Received January 16, 1987
Accepted February 25, 1987