Somatic markers, working memory, and decision making

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The somatic marker hypothesis formulated by Damasio (e.g., 1994; Damasio, Tranel, & Damasio, 1991) argues that affective reactions ordinarily guide and simplify decision making. Although originally intended to explain decision-making deficits in people with specific frontal lobe damage, the hypothesis also applies to decision-making problems in populations without brain injury. Subsequently, the gambling task was developed by Bechara (Bechara, Damasio, Damasio, & Anderson, 1994) as a diagnostic test of decision-making deficit in neurological populations. More recently, the gambling task has been used to explore implications of the somatic marker hypothesis, as well as to study suboptimal decision making in a variety of domains. We examined relations among gambling task decision making, working memory (WM) load, and somatic markers in a modified version of the gambling task. Increased WM load produced by secondary tasks led to poorer gambling performance. Declines in gambling performance were associated with the absence of the affective reactions that anticipate choice outcomes and guide future decision making. Our experiments provide evidence that WM processes contribute to the development of somatic markers. If WM functioning is taxed, somatic markers may not develop, and decision making may thereby suffer.

One of the most consistent challenges of daily life is the management of information in order to continually make decisions about courses of action. Even simple decisions have a potentially bewildering array of options and pertinent dimensions that need to be evaluated for making the best decision. Indeed, it has been claimed by a number of prominent theorists that optimal decision making, in the strict sense, is a practical impossibility. The best that can be hoped for under realistic conditions is decision making based on constrained optimal solutions, using satisficing strategies or simplified decision-making heuristics (e.g., Goldstein & Hogarth, 1997).

With a properly functioning frontal cortex, everyday decision making is challenging enough. But when frontal executive processes are compromised, decision-making effectiveness will dramatically decline (Fuster, 1999; Lezak, 1995). A striking example of loss of effective decision making appears in patients with damage to the ventromedial prefrontal cortex (VMPFC; Bechara, Damasio, & Anderson, 1994). Such people typically retain general intellectual ability and memory but lose the ability to make appropriate decisions in daily life. Instead of a reasonable weighting of short-term and long-term consequences of action, patients with VMPFC damage show a pattern of decision making described as "myopia for the future" (Bechara, 2001; Bechara, Tranel,

& Damasio, 2000). That is, decision making is guided by the immediate outcomes of actions, without regard to what the course of action may have as its issue in the future. In daily life, VMPFC patients often make financial decisions that quickly squander monetary resources. Moreover, these patients make spur-of-the-moment decisions about actions in interpersonal settings or social groups that seriously disrupt long-term social relations (Damasio, 1994, 1998). Despite the pattern of bad decisions, VMPFC patients may be unaware that their decision making is flawed, or they may be unable to modify their decision making when others point out problems (Bechara, Tranel, & Damasio, 2000).

Damasio's work with VMPFC patients has yielded a theory of decision making called the *somatic marker hypothesis* (Bechara, Damasio, & Damasio, 2000; Damasio, 1994; Damasio, Tranel, & Damasio, 1991; Tranel, Bechara, & Damasio, 2000). The theory argues that affective somatic states associated with prior decision outcomes are used to guide future decisions. For example, when a choice followed by a bad outcome occurs, an affective reaction becomes associated with that choice. Once the affective reaction is sufficiently well established, the reaction occurs before a choice is made. Anticipation of a bad outcome before the bad choice is made prevents the bad choice and leads, instead, to a better choice. Thus, a somatic marker of good and bad options guides and sustains optimal decision making. According to this theory, optimal decision making is not simply the result of rational, cognitive calculation of gains and losses but, rather, is based on the good or bad emotional reactions to prior outcomes of choices.

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In essence, rational choice is guided by emotional reactions that bias decision making. Somatic markers help to simplify and reduce the complexity of decision making.

Damasio and colleagues' work with VMPFC patients has been aided by the development of a laboratory test, based on a gambling scenario, that can identify decision-making problems in VMPFC patients (Bechara et al., 1994). In the Bechara gambling task, a person gambles a hypothetical stake of money. On successive trials, the person makes a choice among four different options that offer probabilistic gains and losses. Two of the four options provide occasional large gains, but these gains are offset by frequent or large losses. The other two options provide smaller gains but less frequent or smaller losses. Optimal decision making in the gambling task requires that a person forego occasional large gains in order to accrue the small gains that are more profitable in the long run. VMPFC patients continually select the options that provide occasional, large short-term gains but that ultimately lead to long-term losses. Control participants quickly learn that the best long-term payoffs come from choosing the options with smaller short-term gains.

Damasio (1998) assumes that the prefrontal cortex (PFC) is required for the integration of somatic states with other information in the decision-making setting, and this assumption provides the basis of his account of the decision making deficits of VMPFC patients. For example, patients with damage to the VMPFC continue to have emotional reactions to gains and losses in the gambling task. But VMPFC damage prevents the integration of affective reactions into markers that guide future decisions. Although VMPFC patients have emotional reactions *after* gambling task choices, they do not develop good or bad affective states that *anticipate* good or bad choices (Bechara, Tranel, Damasio, & Damasio, 1996). As a result, they continue to make bad choices based on short-term consequences, because they have no emotional biasing signals that steer them away from the bad choices. Without somatic markers, the informational and attentional demands of decision making in the gambling task are too great, and poor decisions are the result.

The relation between suboptimal decision making in the gambling task and affective, emotional reactions has been illustrated in a number of studies using skin-conductance response (SCR) as a measure of affective state (Bechara et al., 1996; Bechara, Damasio, Damasio, & Lee, 1999; Bechara, Damasio, Tranel, & Damasio, 1997). VMPFC patients, like non-brain-injured people, have affective reactions after being presented with an emotion-laden event. At the beginning of the gambling task, when the participant is learning the outcomes associated with each option, both VMPFC patients and normal controls show SCRs after good and bad outcomes. Later in the session, normal controls develop SCRs that occur prior to the selection of good and bad choices. These anticipatory SCRs occur before the participants can fully verbalize their understanding of the choice contingencies. Thus, the SCR anticipates the choice and biases future decision making.

VMPFC patients, on the other hand, do not develop these anticipatory SCRs, just as they never develop optimal decision making during the gambling session. Absence of the biasing somatic marker corresponds to a continuing pattern of suboptimal choice.

Although Damasio's work has established the importance of somatic markers in specific forms of brain injury, it is still not clear how somatic markers are related to other executive functions of the frontal cortex. For example, one of the most important sets of functions of the frontal cortex is to provide for working memory (WM; e.g., Miller & Cohen, 2001). The term WM refers to that part of the cognitive system that is used to hold a limited amount of information in the focus of attention (Smith & Jonides, 1999). For example, a prototypical WM task is one in which you must actively keep several items in mind and compare them with a test item to see whether the items in memory match the test item. Frontal lobe damage often results in deficits that are specific to the executive control aspect of WM, which controls attentional allocation as information is manipulated (e.g., Fuster, 1999; Shallice & Burgess, 1991).

Damasio and colleagues have argued that decision making guided by somatic markers and WM functions are separate. In their view, ventral regions of the PFC support decision making based on somatic markers, whereas dorsal regions of the PFC support WM function (Bechara, Damasio, & Damasio, 2000). Their argument is partially supported by the finding that VMPFC patients can show normal performance on a delayed response task, indicative of normally functioning WM, while still showing poor decision making in the gambling task (Bechara, Damasio, Tranel, & Damasio, 1998). Although it is certainly true that patients with VMPFC damage may lack the ability to develop somatic markers regardless of WM function, it may nevertheless be true that, under normal circumstances, WM contributes to the development and use of somatic markers. Indeed, Damasio has shown that VMPFC patients with damage that includes more posterior frontal regions will have more severe decision-making problems and WM deficits (Bechara et al., 1998). Moreover, the most recent investigations of patients with frontal cortex damage have shown that ventral and dorsal regions of the frontal cortex interact in decision making (Manes et al., 2002). As a result, when WM function is clearly impaired in frontal patients, decision-making ability suffers all the more.

It is difficult to evaluate how WM and somatic markers interact in the Bechara gambling task, because the task is necessarily simplified for use with the rather impaired population studied. Under more realistic and demanding circumstances, a lack of WM resources may have an important, and unavoidable, impact on decision making. That impact may be manifest either despite the availability of somatic markers or through interference with the establishment of somatic markers.

The present work had two primary purposes. First, we tested whether WM deficits impaired performance on a

more sophisticated version of the Bechara gambling task that was appropriate for intact individuals. Second, we examined the relationship between WM processes and the development of somatic markers. Because our intent was to investigate these processes in a population without serious neurological impairment, we experimentally manipulated the availability of WM resources by having people perform the gambling task with and without extrinsic WM loads. Since the introduction of techniques for manipulating WM capacity by Baddeley and Hitch (1974), the use of an extrinsic memory load in a dual-task paradigm has been a common way to establish the involvement of WM in thought and language processes (e.g., Ashcraft & Kirk, 2001; Baddeley, 1996; Just & Carpenter, 1992; Toms, Morris, & Ward, 1993). Typically, in the dual-task conditions, a participant is required to maintain a digit or letter string in memory while performing the task of primary interest. It is clear from a variety of studies that such digit loads do not merely occupy a verbal buffer but, rather, consume considerable attentional resources that are allocated by the central executive component of WM (e.g., Baddeley, Chincotta, & Adlam, 2001; Toms et al., 1993). By having participants perform the gambling test with and without such extrinsic loads, we were able to test whether normal levels of WM resources are necessary for good performance on the task.

EXPERIMENT 1

The modified version of the Bechara gambling task used in this experiment retained key features of the original, such as the probabilistic nature of gains and losses, options that offered large short-term gains that ultimately led to long-term losses, and options that offered small short-term gains that accrued long-term gains. The major change in our modified task was that the overall payoffs were less extreme, making it more difficult to identify the good option. Also, between the extremes of the good and the bad options, there was an intermediate option that produced long-term gains rather than losses, but gains of much smaller magnitude than those of the best option.

To determine whether the interference of a WM load would affect performance on the modified gambling task, we employed the typical digit load task and a version of a random number generation that had been used by Baddeley (Baddeley, Emslie, Kolodny, & Duncan, 1998) to tax the central executive. Performance of the primary gambling task in conjunction with these secondary WM tasks was compared with a control condition that had similar response requirements but did not require maintenance of information in WM.

Method

Participants. The participants were 38 introductory psychology students at Washington State University, who were partially fulfilling a research participation requirement.¹ The participants were between the ages of 18 and 24 years and were 55% female.

Procedure. The participants were given a brief oral description of the task, which can be paraphrased as follows:

In this experiment, you will be asked to make hypothetical gambles similar to those made in a card game. You will start with a fixed sum of money, and the computer will prompt you to make repeated choices. For each choice, you will sometimes lose money and sometimes win money. Your task is to discover the best way to make choices so that, at the end of the session, you will have the highest amount of money possible.

You will also be asked to perform some additional cognitive tasks while you are making your choices. In one block of trials, a string of five numbers will be presented to be remembered, such as "Remember 25341." Rehearse the five numbers so that you will be able to retain them during the money judgment task. After your money judgment, you will be prompted to respond, such as "The number to the right of 5." In this case, the correct response is "3." Make the response "3" on the numeric keypad. In another block of trials, we will ask you to generate a random number selected from the numbers 1 to 9. Pretend we have placed 9 ping pong balls in a barrel and mixed them. Select one and use keypad response 1 to 9 to indicate the selection. Place the ball back in the barrel, mix them up, and select again when asked for another random number. In another block of trials, after your choice, a number will be displayed, and you will be asked to make that response on the numeric keypad.

The participants were seated in front of individual computer terminals and were told to begin when ready. A program written in Microsoft Basic provided written instructions and practice trials to illustrate the procedure and collected all data from the experiment. The participants could practice as much as they wished, although most people took only a few practice trials to familiarize themselves with the procedure.

Each participant was given three blocks of 80 trials, randomly ordered, with rest between blocks as desired. On each gambling trial, the computer gave a choice among three options. These options were displayed as three rectangles, each roughly the area of a playing card, colored red, blue, or green, with the number 1, 2, or 3 in the middle. Outcomes for choices were based on random selection among a set of gains and losses. One choice, which we will refer to as the *good* option, produced small gains with even smaller losses; another choice, referred to here as the *bad* option, produced larger gains with even larger losses; and another option, referred to as the *intermediate* option, produced small gains offset by smaller losses. Table 1 provides a summary of the choice outcomes arranged for the three options.

The positions of the good, intermediate, and bad options were randomized across each block of trials. Displayed below the gambling options was the current tally of money, which at the beginning of each block was \$2,000. The computer waited for a choice to be made by the participant's pressing the corresponding key on the numeric keypad. Once a choice was made, the color of the option was replaced by white lettering on a black background, which stated "You won \$X" or "You lost \$X," where X was the amount gained or lost on that trial. The tally immediately changed, and there was a pause of about 1.5 sec for the participant to note the results of the choice.

In the digit maintenance condition, before each gambling choice, the participants were given a string of five digits composed of the numbers 1 to 5 randomly arranged and were asked to retain the digit string until the gambling judgment had been made. After making a gambling choice, the participants were asked to identify the digit to

Table 1
Payoff Parameters for Choices in Experiment 1

Choice Type	Min	Max	<i>M</i>	<i>SD</i>	<i>P</i> (Loss)
Good	-25	50	25	28	.2
Intermediate	-100	75	12	68	.5
Bad	-250	100	-25	135	.5

the right of a randomly selected digit in positions 1 through 4. In the randomization condition, after making a gambling choice, the participants were asked to generate a randomly selected number from 1 to 9. The idea here was that, to avoid generating stereotypic sequences, the participant would have to carry over information in WM about previous numbers generated as they performed the gambling task. Note that this differs from Baddeley's implementation of the task in that the typical implementation requires that the participant generate a new number every second (e.g., Baddeley et al., 2001). We believed that using this high response rate would make this condition difficult to compare with the other conditions in the experiment. In the keypad response condition, after making a gambling choice, a number from 1 to 9 was displayed, and the participant was asked to press the corresponding number on the numeric keypad. Thus, no information had to be maintained during gambling choices for this control condition.

Results and Discussion

We first examined performance on the secondary tasks, to ensure that the participants were adequately performing both required tasks. In general, the participants were able to perform the digit maintenance task without too much difficulty. Most people made a few errors across the 80 trials ($M = 13.7$, $SD = 13.5$). As an index of quality of randomization, we used a first-order redundancy measure² (see Baddeley et al., 1998) ($M = 16.5$, $SD = 8.1$). These results are about the same as those obtained by Baddeley et al. (1998) with a forced generation of random numbers every 1.5 sec. No index of quality of the keypad response task was used, because trials did not proceed until a correct keypad response had been made and all the participants had made the correct response quickly.

Figure 1 shows the proportion of choices of the good option across 20 trial blocks for each secondary task condition. Differentiation in performance among tasks occurred by Trials 61–80. This is about the same number of trials as that required for stable choice on the original Bechara gambling task. A repeated measures analysis of variance (ANOVA) for good choices across the four 20-trial blocks confirmed a significant effect of block [$F(3,111) = 3.873$] at an alpha level of .05, used for this and all subsequent analyses. Simple contrasts between first and successive 20-trial blocks showed a significant change in good choices in the keypad task condition [$F(1,37) = 7.721$], but no significant changes in selection of good choices for either digit maintenance or randomization conditions. Thus, gambling performance improved reliably across blocks of trials only for the keypad secondary task. Within each secondary task condition, a Pearson correlation showed no significant relation between selection of good options and number of digit errors ($r = -.13$) or redundancy score ($r = -.02$). Thus, there was no evidence of a tradeoff in accuracy between the primary and the secondary tasks.

Figure 2 shows mean choice proportion for good, intermediate, and bad options during the last 25 trials of each secondary task condition. Choice performance was clearly superior in the keypad task, whereas performances in the two other secondary task conditions were roughly equivalent. A repeated measures ANOVA for good choices across the three secondary task conditions confirmed a significant effect of secondary task [$F(2,74) = 4.184$].

Figure 1. Mean proportion of good choices across 20 trial blocks for digit maintenance (open), randomization (hatched), and keypad (solid) secondary tasks in Experiment 1. Error bars are the standard errors of the mean.

Figure 2. Mean proportion of good (open), intermediate (hatched), and bad (solid) choices over the last 25 trials for the three secondary task conditions in Experiment 1. Error bars are the standard errors of the mean.

Simple contrasts indicated that selection of good choices was significantly greater in the keypad task as compared with digit maintenance [$F(1,37) = 8.071$], and significantly greater in the keypad task as compared with randomization [$F(1,37) = 7.293$]. The mixture of choices was similar for the digit maintenance and the randomization secondary task conditions, with relatively large proportions of bad and intermediate choices. During all the secondary task conditions, there was continual sampling of the bad and intermediate choices. Although there was some difference in the mixture of bad and intermediate choices, this difference was not statistically reliable.

In summary, secondary tasks differed in their impact on choice performance. Maintaining a digit string during the trial interval or generating random numbers across intervals resulted in poorer gambling performance, as compared with the keypad control condition. Therefore, we have established that secondary tasks that load WM result in poorer gambling choices.

EXPERIMENT 2

In Experiment 2, we examined the relation between choice performance in the three secondary task conditions and affective state as measured by SCR. Damasio's somatic marker hypothesis maintains that affective signals bias decision making. Furthermore, Damasio argued that this biasing function can be dissociated from WM functions. That WM deficits created by an extrin-

sic WM load impaired gambling performance having already been established, there were two possible outcomes for Experiment 2 that were interesting to consider. A first possibility was that the participants would develop somatic markers in all secondary task blocks but that gambling choices would be poorer when WM resources were taxed. This result would indicate two independent contributors to decision making: one cognitive and the other affective. If this were the case, the presence of a somatic marker by itself would not ensure good decision making, because WM load could interfere with decision making. A second possibility was that somatic markers would develop only in those cases in which choice performance was good—namely, when WM resources were not taxed. This result would indicate two interdependent contributors to decision making, with the affective component influenced by the cognitive component. That is, the somatic marker would be most likely to develop in conditions of lower WM load.

Method

Participants. The participants were 45 introductory psychology students at Washington State University, who were partially fulfilling a research participation requirement. The participants were between the ages of 18 and 24 years and were 56% female.

Gambling task procedure. The gambling task procedures and instructions were the same as those in Experiment 1, with the following exceptions. The number of trials was increased from 80 to 100. The timing of individual trials was changed somewhat to accommodate SCR measurement. And each participant was given a brief oral description of the skin conductance measure.

Skin conductance response measurement. SCR was recorded by means of a Contact Precision Instruments SC5 SA skin conductance monitor. Conducting electrodes about 1 cm in diameter were attached to the left hand on the interior of the medial phalanx of the index finger and the middle finger. A drop of conductivity gel was applied between the skin and each of the two electrodes to ensure consistent ohmic contact. The electrodes were secured to the fingers by specialized double adhesive tape rings. Every 0.05 sec, the computer sampled a serial port that provided continuous skin conductance level (SCL) in microsiemens. Each SCL sample and a real-time marker were retained for later analysis.

For analysis of affective responsiveness, we measured changes in SCR amplitude (e.g., Dawson, Schell, & Filion, 2000). At the beginning of each trial, SCL was sampled to establish the baseline level for that trial. The baseline SCL value was the mean for SCL samples taken during the beginning 0.5 sec of the trial. SCL was then continuously sampled until a gambling choice was made, to determine peak SCL. The SCR amplitude for the trial was calculated as the difference between peak SCL and baseline SCL on that trial. Any difference between peak SCL and baseline SCL of less than 0.01 microsiemen was considered to be no response on that trial.

The specific timing of the SCR amplitude measure depended on the secondary task and on the latency of each participant's choices during the primary gambling task and the secondary WM tasks. The sequence of events for the trials in each secondary task condition was as follows: (1) *keypad task*, 1.5-sec delay—gambling choice—1.5-sec display tally—keypad response; (2) *randomization task*, 1.5-sec delay—gambling choice—1.5-sec display tally—choose number; (3) *digit maintenance task*, 1.5-sec delay—2-sec digit string—gambling choice—1.5-sec display tally—recall digit.

SCR amplitude was measured between the beginning of each trial and the occurrence of a gambling choice. Accordingly, the time interval was 2 sec longer when a digit string had to be retained during a trial. The average times over which SCR amplitude was measured were $M = 5.36$ sec ($SD = 0.65$) for the keypad task, $M = 5.25$ sec ($SD = 0.62$) for the randomization task, and $M = 7.58$ sec ($SD = 0.70$) for the digit maintenance task. The average duration of each trial, which included the time taken to display the outcome of the gambling choice and performance of the secondary tasks, was $M = 8.03$ ($SD = 1.12$) for the keypad task, $M = 8.14$ ($SD = 0.84$) for the randomization task, $M = 10.57$ ($SD = 1.04$) for the digit maintenance task.

We used SCR amplitude for several reasons. To begin with, SCR amplitude is a commonly used measure in a wide variety of settings (e.g., Siepmann, Muck-Weymann, Joraschky, & Kirch, 2001; Taylor, Carlson, Iacono, Lykken, & McGue, 1999; Tranel & Damasio, 1989). Furthermore, although the time between successive SCRs was relatively short in this experiment, between 5 and 10 sec, individual SCRs were fairly well defined. Rather than making complicated assumptions about the form of the SCR in order to separate potentially overlapping SCR profiles (see Lim et al., 1999) it was simplest to measure amplitude. Finally, the distribution of SCR amplitudes was not seriously skewed, as is often the case with SCR measures (Dawson et al., 2000). Therefore, we were not obliged to transform the data values in order to apply conventional statistical analyses.

Results and Discussion

As in Experiment 1, all the secondary tasks were performed without great difficulty. The change from 80 to 100 trials did not appear to make any difference in either digit maintenance errors ($M = 13.9$, $SD = 12.4$) or randomization indexed by first-order redundancy scores ($M = 15.7$, $SD = 8.1$). A Pearson correlation showed no significant relation between choice of good gambling options within each trial block and number of digit errors

($r = -.05$) or redundancy score ($r = .22$), once again indicating no tradeoff in performance between the gambling and the secondary tasks.

Figure 3 shows the mean proportion of good choices during the last 25 trials of each secondary task condition. The results replicated those of Experiment 1. Digit maintenance and randomization secondary tasks produced poorer gambling choices than did the control keypad task. Gambling performances for digit maintenance and randomization were again equivalent. A repeated measures ANOVA of good choices across the three secondary task conditions confirmed a significant effect of task [$F(2,88) = 3.578$]. Simple contrasts indicated significantly more good choices in the keypad task, as compared with digit maintenance tasks [$F(1,44) = 6.888$] and randomization tasks [$F(1,44) = 6.227$].

SCR amplitudes were analyzed for Trials 26–75 in each secondary task condition. Our analysis is, therefore, of *anticipatory* SCR, in two different senses. First, for each trial, we measured an affective response that occurred before a gambling choice. Second, we measured affective response during early trials within each secondary task condition, before gambling choice performance reached its asymptote. Note, too, that examining earlier rather than later trials was important, to try to ensure that all three choice options were still being sampled and could, therefore, provide meaningful SCR comparisons across these options.

Figure 4 shows mean SCR amplitude for each type of gambling choice, grouped by secondary task. SCR amplitude for good choices was about the same in all the secondary tasks, whereas SCR amplitude for bad and intermediate choices appeared relatively lower in the keypad task. This observation was confirmed by a repeated measures ANOVA in which SCR amplitude for each choice type (good, intermediate, and bad) was examined separately for each task type. The analysis showed a significant change in SCR amplitude across secondary task type for intermediate choices [$F(2,88) = 6.377$] and bad choices [$F(2,88) = 5.15$]. There was no significant change in SCR amplitude for good choices across the secondary tasks [$F(2,88) = 0.377$].

If one examines within secondary tasks, Figure 4 shows no obvious differences among SCR amplitude for good, bad, and intermediate gambling choices for the digit maintenance and randomization. But SCR amplitude for good gambling choices is relatively greater in the keypad task. That is, Figure 4 shows a differential SCR amplitude between the good and the other gambling choices only in the keypad condition. A repeated measures ANOVA in which SCR amplitude for gambling choices was examined within each secondary task condition revealed no significant differences for digit maintenance and randomization conditions. But there was a significant difference in SCR amplitude for the three gambling choices in the keypad task [$F(2,88) = 5.03$]. Simple contrasts revealed that SCR amplitude for good choices was reliably greater than SCR amplitude for either bad choices [$F(1,44) = 5.867$] or intermediate choices [$F(1,44) = 8.676$]. Thus,

Figure 3. Mean proportion of good (open), intermediate (hatched), and bad (solid) choices over the last 25 trials for the three secondary task conditions in Experiment 2. Error bars are the standard errors of the mean.

there was a differential SCR for good choices only in the keypad condition. In the digit maintenance and randomization conditions, there was no differential SCR to good, bad, and intermediate gambling choices.³

Another way to examine the importance of SCR is to identify the best predictor of gambling performance. If the participants were developing somatic markers that biased the decision process, these markers should appear as SCR differences between conditions. These differences should predict gambling choices. Accordingly, for each task, we computed difference scores for all pairwise combinations of good, intermediate, and bad gambling choice proportions. In addition, pairwise difference scores for SCR for good, bad, and intermediate choices, as well as mean SCR amplitude across all choices within each task condition, were computed. Each choice difference score was used as the dependent variable in a stepwise regression analysis. Difference scores for SCR amplitude and the overall SCR amplitude within the secondary task condition were entered as predictors in the regression model. The results of this analysis are shown in Table 2. For digit maintenance and randomization tasks, the single best predictor of gambling performance was the difference between SCR for good and intermediate options. Predictors for the keypad task were different, in that overall SCR and the SCR difference between bad and intermediate choices were most important.

It appears that differential SCR among gambling choices is indicative of better performance on the gambling task. But SCL may also indicate general arousal or a stress

reaction. It is possible that our WM load conditions produced a generally elevated SCL that made it difficult to observe a differential SCR among choices. To examine this possibility, we computed mean SCL over each gambling trial and obtained an average for each secondary task condition. The SCL levels for each condition—keypad ($M = 22.97$, $SD = 2.17$), randomization ($M = 23.16$, $SD = 2.12$), and digit maintenance ($M = 23.24$, $SD = 2.26$)—were not abnormally high. Furthermore, there was no reliable change in mean SCL level across secondary task.

To determine whether high overall SCL levels predicted low differential SCR among choices, we com-

Table 2
Significant SCL Predictors for Stepwise Regression of Gambling Choices in Experiment 2

Choice Difference Score	SCL Predictor	Regression Weight	R ²
Digit maintenance			
Good–bad	good–intermediate	.46	.21
Good–intermediate	good–intermediate	.57	.33
Intermediate–bad	none	–	–
Randomization			
Good–bad	good–intermediate	.34	.12
Good–intermediate	good–intermediate	.37	.14
Intermediate–bad	none	–	–
Keypad			
Good–bad	none	–	–
Good–intermediate	overall SCL	.36	.13
Intermediate–bad	intermediate–bad	.47	.22

Figure 4. Mean skin-conductance response (SCR) amplitude before good (diamond), intermediate (square), and bad (circle) choices over Trials 26–75 for the three secondary task conditions in Experiment 2. Error bars are the standard errors of the mean.

puted pairwise difference scores for SCR amplitude for good, bad, and intermediate choices for each participant for each secondary task condition. Then we obtained Pearson correlation coefficients relating all combinations of mean SCL and SCR difference scores in each secondary task for each individual. Mean SCL in each secondary task was positively and strongly related to mean SCL in the other secondary task conditions ($r = +.9$ or greater for all three correlations). But there were no significant correlations between mean SCL and SCR amplitude difference scores. Thus, we found no evidence that the WM load manipulations were producing a general arousal or stress response that made it difficult to observe a differential SCR. SCR differences were related to WM load, but not to overall SCL.

In summary, decision making was better in the task in which there was a prominent SCR difference. And as in Bechara's earlier studies (Bechara et al., 1997; Bechara et al., 1996, the observed relation between SCR and decision making was anticipatory, in that SCR before a choice occurred predicted gambling performance. In those WM load secondary tasks that produced poorer decision making, there was a corresponding absence of anticipatory SCR differences among choices. These data support the hypothesis that in the gambling task, the WM system and the affective system responsible for the development of somatic markers are interdependent. In fact, adequate available WM resources are needed to develop the affective markers that guide decision making.

EXPERIMENT 3

The results of Experiment 2 were consistent with prior studies by Bechara, Damasio, and colleagues, in that the development of a somatic marker predicted better performance in the modified gambling task. However, there were some differences in both the procedures and the results obtained in Experiment 2 and the procedures and results of prior gambling task studies. For example, Bechara typically used long intertrial intervals when recording SCR (Bechara et al., 1997; Bechara et al., 1996). In Experiment 2, the time between choices was relatively longer for the digit maintenance secondary task. This would reduce the opportunity for overlapping SCRs on consecutive trials, as compared with randomization or keypad tasks. Even though we found the clearest SCR differences in the low WM load keypad secondary task, one might reasonably expect that shorter intertrial intervals would make it harder to detect SCR amplitude differences. Also, previous work has typically shown that SCR to bad choice options is larger than SCR to good choice options (Tranel et al., 2000). On the contrary, in Experiment 2 we found that SCR was greater for the *good* option. A similar finding was reported in a recent study that varied the payoff properties of options in the Bechara gambling task (Bechara, Dolan, & Hindes, 2002). On the basis of these findings, it is possible that rather than always favoring the worse options, the relative size of SCR may reflect the most salient choices of those available. In

Table 3
Payoff Parameters for Choices in Experiment 3

Choice Type	Min	Max	<i>M</i>	<i>SD</i>	<i>P</i> (Loss)
Good	-25	50	25	28	.2
Bad	-250	100	-25	135	.5
Worst	-275	75	-50	135	.5

the original gambling task, the focus is on avoiding the bad options. But in Experiment 2, the intermediate option produced gains rather than losses. Thus, the more difficult aspect of decision making was not identifying the bad option but, ultimately, choosing between the intermediate and the good options. Experiment 3 made two procedural changes to address these differences. We standardized the trials in all the secondary tasks so that the time between SCRs would be more consistent. And we changed the balance of good and bad options by providing one good choice that offered ultimate gains and two choices that yielded ultimate losses.

Method

Participants. The participants were 47 introductory psychology students at Washington State University, who were partially fulfilling a research participation requirement. The participants were all between the ages of 18 and 24 years and were 58% female.

Procedure. The procedures and instructions for Experiment 3 were the same as those in Experiment 2, with two exceptions. First, we standardized events within each trial so that timing for primary and secondary task conditions was as close to identical as possible. The sequence of events for the digit maintenance task was identical to that in Experiment 2. For the randomization and keypad tasks, prior to each gambling choice, the instruction "Please wait for the next trial to begin" was displayed for 2 sec. This change was made so that any potential overlap in SCRs across successive trials would be comparable for each secondary task condition. The sequence of events for each secondary task in Experiment 3 was as follows: (1) *keypad task*, 1.5 sec delay—2 sec wait—gambling choice—1.5 sec display tally—keypad response; (2) *randomization task*, 1.5 sec delay—2 sec wait—gambling choice—1.5 sec display tally—choose number; and (3) *digit maintenance task*, 1.5 sec delay—2 sec digit string—gambling choice—1.5 sec display tally—recall digit.

The average times over which SCR amplitude was measured were $M = 7.37$ sec ($SD = 0.64$) for the keypad task, $M = 7.43$ sec ($SD = 0.65$) for the randomization task, and $M = 7.76$ sec ($SD = 0.86$) for the digit maintenance task. The average duration of each trial, which included the time taken to display the outcome of the gambling choice and performance of the secondary tasks, was $M = 10.12$ ($SD = 0.99$) for the keypad task, $M = 10.11$ ($SD = 1.13$) for the randomization task, and $M = 10.36$ ($SD = 1.29$) for the digit maintenance task.

A second change in procedure was that Experiment 3 provided two bad gambling options (i.e., choices leading to ultimate losses) and one good option (i.e., choices leading to ultimate gains). A summary of the choice outcome parameters is shown in Table 3. Choices in Experiment 3 were now labeled *good*, *bad*, and *worst*.

Results and Discussion

As in Experiment 2, all the secondary tasks were performed without difficulty. For the digit maintenance task, errors for the 100 trials were generally low ($M = 16.7$, $SD = 14.0$). First-order redundancy during the randomization task was somewhat lower than that in Experiment 2 ($M = 12.7$, $SD = 5.5$). A Pearson correlation

showed no significant relation between choice of the good option within each trial block and the number of digit errors ($r = -.21$) or redundancy score ($r = .24$).

Figure 5 shows the mean proportion of good choices during the last 25 trials of each secondary task condition. The overall results are similar to those in Experiment 2, with one exception. Digit maintenance again produced poorer gambling choices, and the keypad task produced the best performance. However, gambling performance during the randomization task was somewhere between the two extremes. A repeated measures ANOVA of good choices across the three tasks confirmed a significant effect [$F(2,92) = 4.801$]. Simple contrasts indicated significantly more good choices in the keypad task, as compared with the digit maintenance task [$F(1,46) = 13.429$], but no reliable difference in good choices between keypad and randomization tasks [$F(1,46) = 2.552$].

Figure 6 shows mean SCR amplitude for each type of choice in the gambling task, grouped by secondary task condition. SCR amplitude for worst choices was about the same in all the secondary tasks, whereas SCR amplitude for good and bad choices appeared to change. A repeated measures ANOVA examining SCR amplitude for each choice type⁴ separately for each secondary task confirmed significant changes for good choices [$F(2,86) = 9.266$] and bad choices [$F(2,86) = 3.672$], but not for worst choices [$F(2,86) = 0.155$].

Figure 6 also shows that only in the keypad condition was there a discernable difference in SCR amplitudes among gambling choices. A repeated measures ANOVA of SCR amplitude for gambling choices within each secondary task indicated that SCR amplitude among choices differed in the keypad task [$F(2,86) = 3.383$], but not in the randomization task [$F(2,92) = 2.284$] or in the digit maintenance task [$F(2,88) = 0.722$]. For the keypad task, simple contrasts indicated that SCR amplitude for worst choice was reliably greater than SCR amplitude for good choices [$F(1,43) = 6.78$]. Thus, the only condition in which there was a differential SCR among gambling choices was in the keypad task. But unlike Experiment 2, the worst gambling choice, rather than the best choice, produced the greatest SCR amplitude.⁵

As in Experiment 2, the relation between choice difference scores, SCR difference scores, and overall SCR within each secondary task condition was examined by using a stepwise regression model. These results are presented in Table 4. For digit maintenance and randomization tasks, the single best predictor of gambling performance was the difference between SCR for good and worst options. The best predictor of gambling performance in the keypad task was overall SCR. These data support the idea that the specific nature of the somatic marker varies depending on the relative discriminability among the choices.

To complete the comparison with Experiment 2, we also examined the relation between overall SCL and differential SCR in different secondary tasks. The SCL levels for each condition—keypad ($M = 22.29$, $SD = 2.08$), randomization ($M = 22.33$, $SD = 1.98$), and digit main-

Figure 5. Mean proportion of good (open), bad (hatched), and worst (solid) choices over the last 25 trials for the three secondary task conditions in Experiment 3. Error bars are the standard errors of the mean.

tenance ($M = 22.81$, $SD = 2.27$)—were not abnormally high and were comparable to those obtained in Experiment 2. Pearson correlation coefficients relating mean SCL and SCR difference scores in each secondary task

revealed the same pattern as that in Experiment 2. Mean SCL in each secondary task was positively and strongly related to mean SCL in the other secondary task conditions ($r = +.9$ or greater for all three correlations). And

Figure 6. Mean skin-conductance response (SCR) amplitude before good (diamond), bad (circle), and worst (square) choices over Trials 26-75 for the three secondary task conditions in Experiment 3. Error bars are the standard errors of the mean.

Table 4
Significant SCL Predictors for Stepwise Regression of
Gambling Choices in Experiment 3

Choice Difference Score	SCL Predictor	Regression Weight	R ²
Digit maintenance			
Good–bad	good–worst	.45	.20
Good–worst	overall SCL	.33	.11
Bad–worst	good–worst	.35	.13
Randomization			
Good–bad	good–worst	.39	.15
Good–intermediate	good–worst	.42	.17
Bad–worst	none	–	–
Keypad			
Good–bad	overall SCL	.30	.09
Good–worst	none	–	–
Bad–worst	none	–	–

there were no significant correlations between mean SCL and SCR amplitude difference scores. Once again, there was no evidence that our WM load manipulations produced a general increase in SCL that obscured differential SCR.

GENERAL DISCUSSION

It should come as no surprise that decision making under conditions of high WM load is more difficult than decision making without such load (e.g., Richardson, 1996). Our results go beyond the obvious, however, in showing an interdependency between WM load and the appearance of a specific, affective biasing signal that can guide decision making. WM load in our studies did not simply interfere with the ability to use the affective biasing signals. Instead, WM load was actually able to prevent the development of these affective signals. Although the somatic marker hypothesized by Damasio may have a distinct neural representation in the ventromedial region of the frontal lobes, the functioning of these markers seems to rely on WM processes in other frontal regions, presumably the dorsolateral PFC.

As in Damasio's studies of VMPFC patients (Bechara, Damasio, & Damasio, 2000; Bechara et al., 1997, 1998), the absence of a somatic marker was associated with poorer decision making. Unlike VMPFC patients, our participants had large-magnitude SCRs in all the experiments. Poor gambling performance was not a result of hypersensitivity to positive payoffs or hyposensitivity to negative payoffs in the WM load conditions. Rather, the operative factor was that in high WM load conditions, a differential affective response to good and bad options was missing. Moreover, this differential affective response reflected the relative value of choices. Therefore, the worst option did not always generate the largest SCR, as was typical in Damasio's studies.

The somatic marker hypothesis was originally developed to explain some of the consequences of frontal lobe lesions, but it can be applied to decision-making problems in other populations as well. The "myopia for the future" described in VMPFC patients is conceptually sim-

ilar to impulsive decision making studied in many other settings (Bechara, 2001; Rahman, Sahakian, Cardinal, Rogers, & Robbins, 2001). That is, people are said to be impulsive decision makers when choices are made for immediate, rather than deferred, outcomes or consequences (Evenden, 1999). As a personality trait, impulsiveness is clearly related to poor choices in real-life situations—for example, risky personal behavior or problems in self-control and suboptimal performance in a wide range of laboratory decision-making tasks (Barratt, 1994; Bickel & Marsch, 2001; Rahman et al., 2001). Impulsiveness is often viewed as a motivational concept in which the value, or affective impact, of immediate reward or punishment outweighs deferred consequences. The concept of impulsiveness loses some of its explanatory luster, because it covers such a wide domain. For example, most people recognize that impulsiveness may involve motor, motivational, and cognitive components (Evenden, 1999; Patton, Stanford, & Barratt, 1995). The explanatory power of the concept of impulsiveness may be enhanced if we are able to more precisely analyze its components.

If Damasio's somatic marker hypothesis is correct, it may be that many types of poor decision making that are labeled impulsive are due to the absence or inefficiency of somatic markers that should be guiding judgment. Consider the example of people with problems of substance abuse. Self-report personality questionnaires and performance on laboratory tasks, including the gambling task, all indicate that people with substance abuse problems tend not to defer immediate gains for long term and, ultimately, more beneficial courses of action (Bechara et al., 2001; Grant, Contoreggi, & London, 2000; Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997; Monterosso, Ehrman, Napier, O'Brien, & Childress, 2001; Petry, Bickel, & Arnett, 1998; Rogers et al., 1999). These people are appropriately labeled as impulsive decision makers. One interpretation of this finding is that people with substance abuse problems have a dysfunction in the executive control system of WM (e.g., Finn, Justus, Mazas, & Steinmetz, 1999). For example, WM limitations, such as low WM capacity, can exacerbate the poorer impulse control that results from excess consumption of alcohol. In contrast, the somatic marker hypothesis suggests another interpretation for impulsivity in decision making. Perhaps, similar to Damasio's frontal patients, people with impulsive patterns of decision making have difficulty establishing the somatic markers that direct the decision process away from poor choices.

Our results suggest that some impulsiveness in decision making may occur because WM dysfunction interferes with the *cognitive* processes that are needed to establish anticipatory *affective* reactions. To the extent that executive processes of WM are resource limited, value may be assessed in a simplified and, ultimately, suboptimal fashion. Accordingly, a subset of people with trait impulsiveness may be those who have inadequate WM resources to assess multiple dimensions of gain and loss that are part of the gambling task. Such a group of peo-

ple would not make bad decisions because they are unable to delay gratification, in the classic motivational sense of impulsiveness. Instead, they would be unable to accurately evaluate the relative value and likelihood of short-term and long-term outcomes. If this analysis is correct, we would expect to find that the larger group of people who are generally identified as impulsive and who are at risk for a variety of real-life problems resulting from poor decision making can be divided into subsets. One of these subsets would include people with compromise of the executive portions of WM. Other subsets might include people who are poor decision makers for fundamentally different reasons.

It is also important to note that WM is a complex and somewhat distributed system with components dedicated to maintaining limited amounts of verbal and visual-spatial information in a highly accessible state and an executive control subsystem that manages the selection of information for further processing, the inhibition of no longer relevant information, and the coordination of feedback with continued information processing (e.g., Miller & Cohen, 2001; O'Reilly, Braver, & Cohen, 1999). When we speak of the present data as bearing on the interdependence of WM and the affective system that produces a somatic marker, we are simplifying a complex relationship. Identifying the specific components of the WM system that are necessary for the development of somatic markers is a priority for future research.

Likewise, as future research uncovers the relations between the WM system and the affective system in more detailed ways, we are likely to develop a much deeper understanding of impulsivity. Although one aspect of the link between WM and impulse control problems may well be inadequate executive control of behavioral inhibition systems (e.g., Finn et al., 1999), impulsive behavior may reflect not only poor inhibition of immediate behavior, but also poor longer term planning and evaluation of future options, owing to capacity constraints that influence the functioning of the affective system that helps to guide or direct decisions.

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NOTES

1. Participants who are fulfilling an introductory psychology credit requirement occasionally make a perfunctory effort. We excluded any participant from further analysis who made extremely rapid responses that reflected no deliberation or serious attempt to properly perform the task. In almost all of these cases, the participant made a single repetitive choice that indicated no attempt to sample among the choices. The number of participants listed in the Method section for each experiment is for those included in the analyses. The number of exclusions was between 3 and 5 for each of the three experiments.

2. Baddeley et al. (1998), and others have discussed many indices that evaluate the quality of randomization, such as second-order redundancy, counting strategies, and digit repetition. We report only first-order redundancy, for simplicity and because first-order redundancy was most strongly related to the other measures.

3. Because Figure 4 reveals a differential SCR amplitude among gambling choices in only one secondary task condition, it is reasonable to interpret this result as an interaction between secondary task and choice type. An analysis could be run as a 3 (secondary task) $\times$ 3 (gambling choice) repeated measures ANOVA, looking for an interaction between secondary task and choice to confirm the observed difference. The reason we did not frame the analysis in this way is because gambling choice type is not a true factor. Gambling choices are dependent measures and are, therefore, not controlled by the experimenter as an independent variable. Beyond this, frequencies of such choices vary among participants, so it is difficult to verify that the data conform to assumptions of the ANOVA. Nevertheless, we can block the results and analyze the data as a 3 $\times$ 3 repeated measures design. The results of this analysis indicate a significant effect of secondary task [$F(2,88) = 8.531$] and a significant interaction between secondary task and gambling choice [$F(4,176) = 2.547$]. This analysis leads to the same conclusion as our analysis of contrasts—namely, SCR amplitude differs among gambling choices only in the keypad secondary task condition.

4. There were four cases in which a participant did not make a single selection of the worst choice in Experiment 3 over Trials 26-75. It would be inappropriate to record SCR to worst choice as zero in these cases. We omitted these cases from the analyses, and this is reflected in the differing degrees of freedom for the ANOVAs that follow.

5. As was discussed in Experiment 2, it is possible to analyze the results as a 3 (secondary task) $\times$ 3 (gambling choice) repeated measures ANOVA. This analysis for Experiment 3 indicates significant effects of secondary task [$F(2,86) = 5.101$] and gambling choice [$F(2,86) = 9.648$]. And as in Experiment 2, there is a significant interaction between secondary task and gambling choice [$F(4,172) = 2.563$].

(Manuscript received April 2, 2002;
revision accepted for publication September 5, 2002.)