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Abstract

A recent matter of debate in the cognitive sciences concerns the role played by emotions in decision making. Bechara et al. (1998) and Turnbull et al. (2005) have argued that making choices involves processes that can be double dissociated from working memory and that are independent of executive functions. These results have been interpreted on the basis of Damasio's (1994) Somatic Marker Hypothesis, which claims that a special circuit involved in processing changes happening in the somatic state is largely responsible for orienting human behavior in the decision process. In this paper, we examine the evidence in favor of this interpretation, as well as of possible alternative accounts. We suggest that interactions should occur between somatic markers and working memory, and we propose an experiment using the Gambling Task where a more appropriate dual task paradigm is employed that exposes the allocation of cognitive resources at different stages of the decision making process. Our results show that executive resources are required for successful decision making in the Gambling Task. We discuss our findings both in the frame of the Somatic Marker Hypothesis and of alternative views.

Introduction

Damasio (1994) convincingly argued that the role of emotions in making decisions had been greatly overlooked. Relying mainly on evidence from frontal patients, he put forward his Somatic Marker Hypothesis, which describes a plausible mechanism through which emotions arise, crucially influence higher cognitive processes and, in turn, determine behavior

The Somatic Marker Hypothesis is based on two principal claims. The first is that emotions originate as perceived changes in one's somatic state, reflected in modifications in the corresponding brain areas. The second claim is that somatic representations, instead of being used only once, are durably associated with the ensuing stimuli and actions—therefore marking them with the corresponding bodily states. Physiologically, this happens by conveying somatic states to a convergence area in the frontal lobes, where higher-level processing of stimuli and top-down control of actions are known to take place.

As a result, somatic representations may be later recalled associatively, causing a transient reenactment of the original experience. This reliving, possibly implicit, is responsible for guiding the decision making.

One of the matters of disputation is the extent to which Damasio's proposed mechanism is implied in decision making, and how much it is independent of other cognitive processes. In this paper, we will deal with this topic, and provide evidence that, while a certain degree of independence is plausible, it should be smaller than previously claimed.

The Gambling Task

One of the motives for the Somatic Markers Hypothesis was the necessity to account for neuropsychological evidence. It is acknowledged that brain damages in the frontal lobe could strongly affect one's decision making capabilities, at least in personal and social domains, and lead an individual to an utterly inappropriate misconduct while, at the very same time, leaving other cognitive functions and intelligence unaffected (Saver & Damasio, 1991). Abnormal behavior in frontal patients was later linked to their pathological lack of emotional appraisal (Damasio, Tranel & Damasio, 1991). These findings hinted at a possible role for emotional functions in decision making.

Frontal patients' misconduct was later captured in a laboratory setting by developing a sequential decision making task known as the (Iowa) Gambling Task (henceforth: GT). The task consists in picking up a card at the time from one of four decks. Participants soon discover that card selections always result in a win which is small for two decks, and twice as big for the remaining ones. However, certain selections may lead, unpredictably, to a monetary loss. Losses are presented immediately after wins, have no fixed schedule or magnitude, and are arranged so that the two decks which carry bigger wins also produce losses so huge to result in an eventual failure. On the contrary, losses in the other two decks do not overthrow the smaller wins, resulting in a net gain. Therefore, the advantageous strategy is to refrain from the bigger wins and stick with the humbler ones.

In their pivotal study, Bechara, Damasio, Damasio and Anderson (1994) found that, while control participants learn to pick from advantageous decks avoiding the others, frontal patients cannot refrain from making disadvantageous selections. The authors later correlated the behavioral changes in controls' decision patterns to changes in the skin conductance responses (Bechara, Tranel, Damasio & Damasio, 1996), a physiological measure thought to reflect the ongoing activation of somatic memories. The lack of such responses in patients hinted at a selective impairment of the somatic marker circuit. Moreover, a subsequent experiment by Bechara, Damasio, Tranel and Damasio (1997) evidenced that the onset of both behavioral and physiological changes anticipated conscious knowledge of the winning strategy. This result seems to imply that the somatic marker mechanism was exerting its long-term beneficial effect implicitly, independently of conscious and controlled cognitive evaluations.

Somatic Markers and Working Memory

The alleged implicitness of the somatic markers action was later questioned by several studies (Tomb, Hauser, Deldin & Caramazza, 2002; Maia & McClelland, 2004). This issue is also related to the extent to which the somatic marker mechanism is independent, or even substitutive, of other cognitive processes usually thought to be responsible for the decision procedure. The position held by Damasio and co-workers seems ambiguous. Sometimes they outline a milder view where somatic markers are required to simply assist the processing of different options (e.g. Bechara, Damasio, Tranel & Damasio, 2005). On other occasions, they seem to suggest that the somatic marker circuit could, by itself, achieve long-term advantageous strategy evaluation (Bechara et al., 1997).

Bechara, Damasio, Tranel and Anderson (1998) later offered substantial evidence for this stronger position. In their experiment, two groups of patients were compared on two different tasks. One group comprised patients with selective damage in the ventromedial area of the prefrontal lobe. Lesions in the other patients were located in the dorsolateral prefrontal cortex. The first region is the convergence area implicated by the somatic marker hypothesis, while the second one is known to be implied in executive functions. The two tasks were the GT and a working memory task. Ventromedial patients performed badly in the GT, but normally in the memory test. On the contrary, dorsolateral patients scored poorly in the memory task, but resulted unpredictably unimpaired in the GT paradigm. The resulting pattern was a double-dissociation between the two groups, which suggested the independence, both functional and anatomical, between decision making and working memory (Bechara et al., 1998).

A more surprising result was put forward by Turnbull, Evans, Bunce, Carzolio, and O'Connor (2005). They presented a study where three groups interacted with the GT. Two of these groups were required to perform a concurrent secondary task, which could be considered as either related (random number generation) or not (reciting aloud the sequence of numbers from 1 to 9) to executive functions. Surprisingly, performance in the GT remained the same across the three conditions, supporting the view that the processes underlying decision making in the GT are dissociable from the executive functions.

The experimental results by Bechara et al. (1998) and Turnbull at al (2005) imply that the action of somatic markers is largely independent of central cognitive resources.

This it is in sharp contrast with different results already acquired in the decision making literature, where working memory capacity is a bottleneck, and the use of simplifying heuristics to reduce workload is widely described (e.g. Payne, Bettman & Johnson, 1993).

Indeed, the GT is a paradigm much more unstructured than the usual artificial decision making settings. Two-step models of decision making have been proposed, where cognitive evaluation is used in structured domains while emotional appraisal is adopted when coping with uncertain and unstructured paradigms (Kahneman, 2003). This latter process seems akin to what Damasio propones.

Alternative Explanations

Although surprising, the results of Turnbull et al. (2005) and Bechara et al. (1998) are not definitive. In the case of Turnbull et al. (2005), we suspect that the lack of effect of the secondary task lies in the interfering task they adopted. Random number generation is a demanding task, but, when carried out self-paced, it allows enough time to allocate resource to the main task. In addition, the participants' performance in Turnbull et al. (2005) was somewhat lower when a secondary task was introduced—although not at a significant level.

The double dissociation reported by Bechara et al. (1998) seems more conclusive. However, there is neuropsychological evidence that the dissociation is not perfect. For instance, half of the ventromedial patients in that experiment also showed abnormal patterns in the working memory tasks (Bechara et al., 1998). In addition, Fellows & Farah (2005) found that dorsolateral frontal patients can be impaired in the GT, and that, conversely, ventromedial patients perform normally under a slightly modified distribution of losses.

In any case, the GT does not constitute a highly demanding task for working memory. Selective recollection for the worst outcomes may be sufficient to hold patients from choosing the riskier decks. As a demonstration, Stocco, Fum & Zalla (2005) proposed a computational model of the task where memory is indeed a component as important as somatic representations in achieving good performance. The model relied on the idea that somatic representations are implicitly used for linking deck selections and ensuing outcomes. Once acquired, associations facilitate cued retrieval of aversive outcomes, making it easier to detect the disadvantageous choices. Although leaving room for a possible role for somatic markers, the model requires central cognitive resources for successful decision making, especially in the early stages when the outcomes from previous choices need to be focused and processed. On the contrary, later recollection may be easier, and unaffected by a simulated reduction in working memory. This allowed for a simulated replication of the apparent dissociation (Stocco, Fum & Zalla, 2005).

The Experiment

Our intuition was that working memory and executive functions do indeed play a role in the GT. We were left to find experimental evidence supporting our view.

As we already pointed out, the GT is rather an unstructured task. This feature is essential for highlighting behavioral disorders in frontal patients, but unfortunately allows few possibilities for controlled manipulations.

However, despite its unrestrained formulation, the GT has some obvious constraints. For our purposes, it is important to observe that decision making occurs in discrete events, and these events are clearly segmented by participants' choices. Each selection is potentially independent from the previous and the following ones. Participants cannot anticipate when the task will terminate, and are clearly informed that they could succeed if they stick to the advantageous choices. The only feedback is given during the small pauses between consecutive selections, when wins and possible losses are presented.

It is clear, therefore, that at each decision cycle, participants perform two operations. First, they must encode and process the result of their previous action, progressively learning the value of the decks. Second, they must ponder the following move. We cannot distinguish easily between the two processes, and probably they are interwoven within the same time span. However, one can selectively *suspend* feedback. This cancels the opportunity for encoding new outcomes and learning from them. As a consequence, the evaluation process alone remains the only activity between two subsequent card selections.

We developed an experimental task that takes advantage of this asymmetry to disentangle the two processes. In our paradigm, participants have to perform an initial interaction phase with the GT for the usual length of 100 trials. This allows for a full replication of the GT experiments, at the end of which the participants' selection behavior should be stable on the advantageous strategy.

This phase is followed by a second phase, during which no feedback is conveyed. Before the beginning of this second period, participants are informed that, although no information is given on their selections, decks' profitableness is unchanged. They are also instructed to continue selecting from the decks they have learned to be the safe ones.

Adding an interfering task to the first or the second phase will result, respectively, in interfering with both learning and deciding, or with the decision phase only (all the learning having already occurred). A possible effect of the secondary task on GT performance will reflect the contribution of executive functions in one of these two components—or in both.

The Interfering Task

To be appropriate, our interfering secondary task had to conform to three criteria. First, the task had not to be self-paced, so that participants could not learn to interleave them in an optimal way. For similar reasons, we needed each trial of our task to be independent of the previous one, to avoid potential effects of learning and anticipation that could alleviate the cognitive workload. Finally, we needed a task that made no use of the same motor or perceptual resources, so that the interference would be limited to the central cognitive resources.

In the end, we opted for a sequential parity discrimination task. Participants were acoustically presented with a series of numbers in the range between 1 and 10. For each number, participants were to indicate whether it was even or odd by pressing one of two buttons.

Possible Results

Given our two-by-two design, there are four possible results of our experiment.

The secondary task has no effect in the first or in the second phase. Such a result implies a complete independence of the activity of somatic markers from attentional resources and, consequently, from high-level, conscious cognitive processes, which are known to be resource-demanding. This would be a strong confirmation of what previously claimed by Turnbull et al. (2005), and by Bechara et al. (1998).

The secondary task affects performance in the first phase, but not in the second one. Associations with experienced somatic states may help aversive results to be recalled during the selection phase, thus orienting one's decision without the need for cognitive resources. However, the learning of such association may require some initial attentive step. For instance, one may need to attend and process the stimuli for a sufficient time for the association to take place, or may need to explicitly perceive one's own change in the somatic state to make it enter the associative process.

The secondary task has no effect in the first phase, but affects performance in the second one. This perspective is the exact opposite of the previous one. It implies that learning in the GT may occur without any contribution of executive functions, but they are needed during the selection phase. Somatic markers would be needed for encoding and processing monetary results, but not in the stage where options are evaluated and a final decision is made. We do not know of any researcher currently endorsing this view.

The secondary task affects performance on both the first and the second phase. This position implies that, in effect, no automatic mechanism exists at all in the GT, and achieving successful performance is possible only by means of resource consuming cognitive elaboration. This would strikingly be at odd with previous experimental results by Bechara et al. (1998) and Turnbull et al. (2005). Although this may be the case for some unemotional and analytic participants (which indeed we encountered in this, as well as in other studies), we think it is not generally the case.

Method

Participants

Participants were 155 students (82 females) from the University of Trieste, aged 19 to 51 (*M* = 22, *SD* = 4.3). Each of them had been previously randomly assigned to one of the four possible conditions obtained by applying the secondary task in the first phase, in the second phase, in none of them, or in both. Data from two participants were lost during a data transfer operation.

Procedure

The GT was performed on a specially developed computer application. The software was a custom-made replica of the original program developed by Bechara, Tranel, and Damasio (2000). Decks were visually presented on a 15" LCD screen, and participants used a mouse device to point and select the deck they had chosen. Wins and losses were presented visually in the upper half of the screen, immediately following each card selection. The running total of money was always visible in the uppermost part of the screen.

The same application was designed to run also the secondary task. Auditory stimuli were presented through a pair of wireless earphones. Participants could respond by pressing two keys on a USB numeric pad placed on the side of the non-dominant hand. They were trained before the beginning of the experimental session. The ten stimuli had been previously recorded from an Italian native speaker female voice, and stored into separate WAV files. The lag between two the onsets of two consequent stimuli was fixed to two or three seconds[1]. Stimuli were randomly selected, with the only constraint that the same stimulus could not occur twice in a row.

The experimental sessions were held individually. The instructions were an Italian translation of the original ones (Bechara et al., 1994), and were presented in written form to all participants. After reading the instructions, participants underwent a first phase of interaction with the computer version of the GT. Participants sat in front of a 15' LCD monitor, and were given a mouse to select the decks on the screen with their dominant hand. When required to complete the secondary task, participants were also given the earphones and the numeric keypad.

Upon completion of the first phase, the application prompted each participant to call the experimenter for further instructions. The experimenter delivered new written instructions, and remained available to answer possible questions.

The chosen payoff matrix for the IGT was the so-called *A'B'C'D'* version described by Bechara, Tranel, and Damasio (2000). In this version, losses increase over time. We opted for that payoff schedule because it seems to favor both healthy participants and frontal patients, therefore providing a stricter test for our hypothesis.

[1] Initially, the interval between stimuli was one of the factors manipulated in the experiment. Subsequent analysis, however, showed that both conditions were sufficiently demanding, and that the different time lag had no effect on GT performance ($F(1,138) = 1.32$) nor interacted with any of the other factors. For clarity's sake, we decided to pool together participants and re-run all the analysis without considering this factor.

Results

We discarded data from seven of our participants, due to their outlying performance in the first phase (more than 2 *SD*s above or below the mean). As it is usual in the GT, we measured performance as the difference between good and bad choices over blocks of 20 consecutive selections. Specifically, we were interested in the performance in the last 20 trails at the end of the first phase, and the 20 selections that made the second one.

Effects of the Secondary Task on Performance

First, we checked the correlation between performance at the end of the first phase and performance in the second phase. They turned out to be significantly positively correlated (Spearman $r = 0.51$, $p < 0.001$), confirming our assumption that performance in the blind period reliably reflected the knowledge acquired during the first series of interactions. To examine the effect of the interfering secondary task, we compared the participants' performance in the last 20 trials of the first phase with performance in the second phase. We run a mixed-design ANOVA using the secondary task in first phase (present vs. absent) and in the second phase (present vs. absent) as between factors, and the phase (first vs. second) as a within factor. Participants' performance was the dependent variable.

The analysis uncovered a significant effect of the secondary task in the first phase ($F(1,149) = 10.31$, $p=0.002$). In fact, in both the first and the second period, the two groups that went through the secondary task in the very first phase performed worse than the other two. On the contrary, performance in the second period was unaffected by the presence of the additional task ($F(1,149) = 2.11$).

Also, we did not find any effect of the phase (first vs. second) at all ($F(1,149) = 2.61$), implying that group performances in the second part were not significantly different from those recorded at the end of the first phase.

Finally, none the two-way interactions was significant (secondary task in the first x in the second phase: $F(1,149) = 0.01$; secondary task in the first phase x phase: $F(1,149) = 0.24$), and neither the three-way interaction reached significance (secondary task in the first phase x in the second phase x phase: $F(1,149) = 0.31$).

These results are summarized in Figure 1. Here, the left panel exhibits the performance of the four groups across the first phase, while the right part depicts their performances at the end of the first phase and during the second one.

As a confirmation, we also run a factorial ANOVA, where only the performance in the second phase was used as a dependent variable.

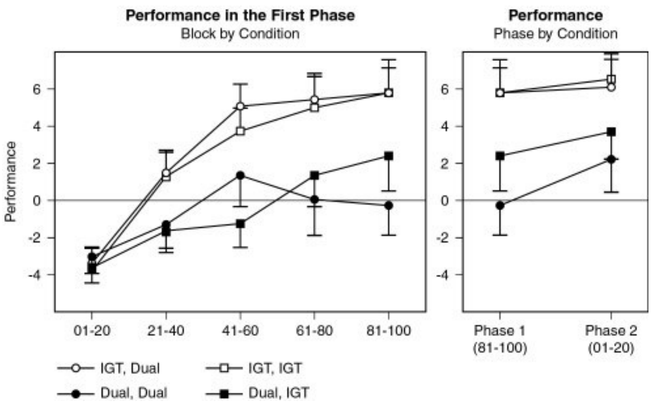

Figure 1: (*left*) Performance of the four groups through the first phase. (*right*) Performance of the four groups at the end of the first phase and during the second phase. Points represent means, bars represent either +SEM (for the groups that did not undergo the dual task condition in the first phase) or –SEM (for the groups who did).

This second analysis replicated our previous results, finding no significant effect but the presence of the secondary task in the first period ($F(1,142) = 5.69$, $p = 0.02$).

Such a pattern of results seems to imply that cognitive resources are required to process adequately the results of card selections, and that an early impediment in this phase precludes subsequent successful decision making. Therefore, we conclude that somatic markers are either irrelevant for decision making (as proposed by Maia and McClelland, 2004), or that their role is dominant only in a later stage, provided that other central cognitive process were involved during the learning process.

As we already pointed out, this may be odds with Bechara's et al. (1998) interpretation of their own data, but it is not inconsistent with their findings: our model can account for both patterns.

What Participants Knew: An Analysis of Latencies

At this point, it is interesting to investigate which kind of knowledge was acquired by participants during the periods when learning occurred. Assuming that the relevant knowledge was *not* simply the sum of perceived somatic changes, we remain with a fistful of possible alternative solutions.

A first candidate explanation is that participants, during the second phase, relied on procedural selections rules acquired during the first series of interaction. Although plausible, this possibility is ruled out by neuropsychological evidence. In fact, we know that patients with Parkinson's disease are impaired in tasks requiring habit learning and procedural skills (Knowlton, Mangels & Squire, 1996). Nonetheless, Stout, Rodawalt and Siemers (2001) showed that they are unimpaired in the GT.

A second option is that participants understood completely the underlying strategy. Once the payoff rule was discovered, following it in the second phase may well be done in spite of a secondary task, explaining its lack of efficacy. Such an explanation is suggested by the analysis of the participants' reports in Bechara et al. (1997) and especially in Maia and McClelland (2004), where performance turned out to be always correlated with explicit knowledge of the underlying rules. However, we suspect that, in both studies, the use of questionnaires during the task may have driven participants to a more elaborate understanding of the underlying rules, leading to an overestimation of the amount of explicit rule-like knowledge they could rely on. In addition, the behavior of our participants does not suggest any rule-following pattern. Even during the second phase, where they could clearly not benefit from exploration, they display a fuzzy series of selections, persevering in sampling from disadvantageous decks more than we would expect if they were really taking advantage of explicit representations of the task.

There is a third, possible view, which is the one we endorsed and implemented in our model. This hypothesis is that participants' selections are guided by memory of previously experienced outcomes, and the evaluation phase is performed mainly by memory sampling.

The second and the third hypothesis may be distinguished by looking at the average latencies in decisions. In particular, we can compare the average latencies in the second phase for participants who did or did not have the secondary task in the preceding period. If participants make their decisions relying on an explicit representation of the task, their selection latencies should be faster, or not significantly slower, when they had the opportunity to learn than when they did not. On the contrary, if participant's decision is based on the outcomes they can recall from the previous phase, then a better encoding should result in larger sampling from memory, requiring longer time for evaluation and, therefore, larger latencies before selecting a deck.

To test this prediction, we analyzed the effect of the interfering task in the first phase on the average decision latency in the subsequent phase. This comparison was limited to those two subgroups that were not in the dual task condition in the second period. To adjust for possible non-normal distribution of response times, the analysis was performed on the square root of the latencies. Participants who did not experience the secondary task in the previous phase (M=36.75, SD = 11.98) were significantly slower than those who did (M = 30.87, SD = 5.00: $t(69) = 2.74$, $p < 0.01$). The corresponding results in milliseconds are reported in Figure 2.

Conclusions

Our results question a stronger formulation of the Somatic Marker Hypothesis, and the purported double dissociation that has been claimed by Bechara et al. (1998) and Turnbull et al. (2005). We think that in both the experiments there were possible alternative explanations for the results, and we showed that a more careful experiment can indeed highlight a role for central cognitive processes.

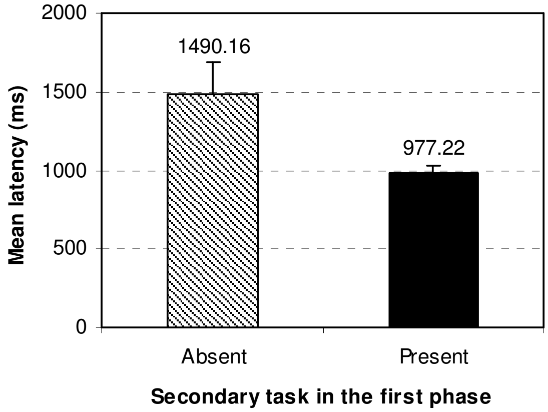

Figure 2: Mean latencies in the second phase for the participants who did or did not experience the secondary task in the first phase. Bars represent mean values +SEM.

Our results are not incompatible with Damasio' hypothesis: in fact, they are consistent with a milder version of the theory where somatic representations are one of the possible signals that a central executive may need to evaluate the consequences of previous decisions.

We do not deny that executive functions and emotions may rely on different circuits. What we find unrealistic is the hypothesis that one of those functions alone is responsible for human decision making. Selecting the appropriate alternative, like any complex activity, requires a successful integration of both sources in order to be achieved. Different settings may make one component more important than another, but we find it difficult to conceive a decision making task that is achieved entirely by somatic marker circuits.

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