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# Emotions elicited by impasses and subgoal achievements in problem-solving.

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RÉSUMÉ.. *Considérer les émotions éprouvées pendant la résolution de problème paraît incontournable pour comprendre et expliquer la nature de cette activité cognitive finalisée. L'objectif de cette recherche est d'étudier l'effet des succés et échecs locaux rencontrés au cours de la résolution sur les composantes physiologiques et expressives de l'émotion. Dix neuf participantes ont été invitées à résoudre un problème de Tour de Hanoï à 5 disques. L'activité électrodermale et les expressions faciales ont été codées en continu pendant la résolution. Les patterns émotionnels spécifiques observés pendant les impasses et les atteintes de sous-buts sont interprétés dans le cadre des théories de l'appraisal et sont discutés comme reflétant l'implication de l'émotion dans ce type d'activité cognitive orientée par des buts.*

ABSTRACT *Taking emotions elicited during problem solving into account is essential to lead to a better understanding of this kind of goal-oriented activity. The present study addresses the effects of failures and successes encountered over the course of a problem on physiological and expressive components of emotion. Nineteen female participants were asked to solve the five-disks version of the Tower of Hanoi problem. The spontaneous skin conductance activity and the facial expressions were recorded without interruption during the problem-solving activity. The specific patterns of emotional manifestations observed during the impasses and the subgoals achievements are interpreted within the framework of the appraisal theories and are discussed as reflecting the implication of emotion in a goal-oriented activity such as problem-solving.*

MOTS-CLÉS : *Émotion, Résolution de Problème, Théories de l'Appraisal, Activité Electrodermale, Expressions faciales*

KEYWORDS: *Emotion, Problem-Solving, Appraisal Theories, Skin Conductance Activity, Facial Expressions*

## 1. Introduction

Several studies in experimental psychology, neuropsychology and neurosciences demontrate that emotion is closely related to cognitive processes as learning, decision making, attention and memory (e.g. Bechara, Damasio, & Damasio, 2000; Corson, 2002; Hänze & Meyer, 1998; Isen, 1999; Öhman, Flykt, & Esteves, 2001). In this way, the assumption that emotion plays a crucial role in social, adaptative and intelligent behavior has become well established (e.g. Cacioppo & Gardner, 1999; Damasio, 1994; Goleman, 1995).

Although there is no doubt emotion and moods influence our problem-solving activities, some interesting questions remain unanswered: Do the significant events such as failures and successes encountered over the course of a problem trigger emotion? How to experimentally evaluate these events during problem-solving? Are there specific emotional patterns related to these events?

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Actually, previous studies, employing a wide range of induction methods, focused on the influence of the affect on strategies. Results show that positive affect facilitates creative problem-solving and leads to use top-down strategies, even when individuals in a negative affect are likely to develop bottom-up strategies and a more systematic processing of information (Ashby, Isen, & Turken, 1999; Fiedler, 2001; Isen, 1998). Yet, a few (if any) study have concentrated on the emotional manifestations elicited by the appraised failures and successes over the course of problem-solving. We address the effects of failures and successes encountered over the cognitive activity on emotional manifestations. Referring to a general model of problem-solving (Richard, Poitrenaud, & Tijus, 1993) we identify the successes and failures during the activity and investigate on line the emotional manifestations that occur in these critical steps of problem-solving.

## 2. Theorical rationale and reseach review

### 2.1. *The identification of the successes and failures encountered in the course of a problem*

#### 2.1.1. *Problem-solving activity*

Problem-solving is commonly viewed as a goal-directed activity. As Duncker claims: «A problem arises when a living creature has a goal but does not know how this goal is to be reached» (1945, p.1). In this way, the activity is clearly organised toward a goal which is not accessible by the application of obvious and well-known operations. Two broad components of the problem-solving process have to be taken into account to understand this activity: the internal mental representation the solver uses to guide his/her activity and the goal generation. New approaches consider that the representation one constructs guides the discovery process (e.g. Novick & Bassok, 2005) and that the identification of this internal representation leads to a better understanding of some apparent inconsistent behaviors (e.g. Clément & Richard, 1997; Sander & Richard, 2005). Although this conception of problem-solving is attractive and psychologically plausible, a main difficulty remains: how to identify the internal representation?

#### 2.1.2. *Problem representation*

The theoretical framework proposed by Richard and collaborators (Richard, Pointrenaud, & Tijus, 1993) is well suited to reply with this question and to model problem-solving behavior in puzzle-like situations such as the Tower of Hanoi, River Crossing or Water Jugs problems. It is assumed that problem-solving consists in elaborating the adequate representation of how the problem has to be solved, by dropping misconceptions (inappropriate interpretations and irrelevant goals generated by these misconceptions) and building more and more sophisticated goal-structures that lead to a planning activity. In this approach, two broad types of events are critical and relevant: the impasse situation in which the current representation leads to the feeling that all the ways to the solution are blocked and the subgoal achievement which objectively draws nearer the goal. These events are supposed to be the opportunity of changing the representation (when the first representation leads to impasse) and the current goal (both when the first representation leads to impasse and when a subgoal is achieved).

#### 2.1.3. *Identification of the impasses and subgoals achievements in the course of a problem*

Like that, by conducting a subject-by-subject analysis, this theoritical framework allows to identify the impasses and subgoals achievements in the course of a problem. As mentioned above, the impasse situation is a state in which the current representation may give the feeling that the problem is unsolvable. Three behavioral signals may accompany these subjective impasses: the interruption of the activity without any action, the looking-back that undoes the previous action, and the rules violation that constits

in making an illegal action. The subgoals achievements are the objective states of the problem that have to be reached to come up to the goal. It is reasonable to think that impasse situations may be appraised as temporary failures and subgoal achievements as successes.

## 2.2. *Emotions, cognitive appraisal and problem-solving*

### 2.2.1. *Emotions*

Although the definition of emotions remains contreversial, some researchers distinguish emotion and others related notions as mood or personnality traits on the basis of their behavioral time course and intensity: emotions are defined as short-lived behavioral dispositions, moods are of longer duration and lower intensity, while personality traits reflect relatively stable behavioral tendencies. Nevertheless, it is generally assumed that emotions may be evaluated by three kinds of responses: the physiological responses which the electrodermal activity and the heart rate are the most widely used, the expressive responses including facial, vocal, gestural and postural expressions and the subjective responses based in part on verbal report (see Bauer, 1998; Boehner, DePaula, Dourish, & Sengers, 2007 for critical reviews).

### 2.2.2. *Emotions and cognitive appraisal*

Appraisal theories suggest that emotion is the result of underlying mechanisms including the subjective evaluation of the significance of a situation and its organism's circumtances (*appraisal*), and the *coping* mechanisms that guide and provide adaptative responses (Frijda, 1986; Lazarus, 1991; Scherer, 1984; Scherer, Schorr & Johnstone, 2001; Smith & Lazarus, 1990, 1993). As noted by Gratch and Marsella: «Appraisal theories posit that events do not have significance in of themselves, but only by virtue of their interpretation in the context of an individual's beliefs, desires, intentions and abilities» (2004, p. 273). The significance of an event is supposed to be evaluated on a number of criteria such as its relevance for one's well-being, its conduciveness for one's plans and goals, and the ability to cope with such consequences.

In the framework of the Scherer's Component Process Model (Scherer 1984, 2001), Sander, Grandjean & Scherer (2005) describe emotion «as an episode of interrelated, sychonized changes in the states of all or most the five organismic subsystems[1] in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism.», (p.318). From this point of view, rather than static and basic states of the organism (e.g. Eckman, 1984; Izard, 1977), emotions are a dynamic process whose components are the cognitive component which function is the evaluation of objects and events, the peripheral efference component which regulates the system, the motivational component which prepares and guides the actions, the motor expression component which steadies commication of reaction and behavioral intention and the subjective feeling component which monitors the internal state and environment interaction. In other respects, this model postulates that changes in one subsystem will tend to elicit related changes in other subsystems.

### 2.2.3. *Elicited emotions in the course of problem solving*

As mentioned above, in the Richard's approach impasse situations and subgoals achievements are assumed to be relevant events in problem-solving: they are the steps in which the current internal representation may be changed in order to head towards the goal. Thus, these events may elicit emotion in

[1] Organismic subsystem (and their major substata are the following) : Information processing (Central Nervous System-CNS-), Support (CNS, Neuro-Endocrine System, Autonomic Nervous System), Executive (CNS), Action (Somatic Nervous System), Monitor (CNS), from Sander, Grandjean & Scherer, 2005.

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the following way: impasse may produce frustration whereas subgoal achievement may reinforce the confidence and the motivation. In other words, these events may be appraised according to their conduciveness or obstructiveness for the goal and therefore may be evaluated as temporary failures and success in the discovery process. Nevertheless, in the theoretical framework of Richard and collaborators, emotion elicited by these events are not taken into account. The present study is a first attempt to fill this gap by examining the effect of these relevant events on emotional manifestations.

The appraisal theories are good canditates to study the triggered emotion in these events because they allow to make predictions on the patterns of the elicited emotional responses. Indeed, it is suggested that appraised events would affect the different subsystems in different way according to their subjective significance. Like this, it may be anticipated that the cognitive evaluation of the impasses as temporary failures and subgoals achievements as successes would have effect on the others subsystems. In this research, we focused on two kinds of response components: the physiological - electrodermal activity- and the expressive - facial expressions - components. Concerning the physiological component, and in particular the electrodermal activity, the study of Pecchinenda and Smith (1996) provides psychological significance of spontaneous skin conductance activity. In these work, participants were given to solve a set of anagrams which difficulty was manipulating by both the objective difficulty (easy, modarately, difficult, extremely difficult) and the amount of time available to solve the problems (30 vs. 120 seconds). The authors demonstrate that the skin conductance activity during problem-solving is correlated to the appraisals of coping potential: in a difficult problem, appraisails of coping potential based on self-report are especially low and produce selective disengagement of the task, yielding reduced skin conductance activity. The spontaneous electrodermal activity is interpretating as reflecting task engagement (Pecchinenda, 2001). Concerning the expressive component, in the present study, facial expressions were chosen as reflecting the appraisal of the goal relevance of the event (Scherer, 1984, Smith, 1989).

### 3. Overview of this study

We tested the influence of the impasses and the subgoal achievements on the physiological and expressive manifestations of the emotion. A five-disks version of the Tower of Hanoi problem was chosen because it is a relatively difficult problem for adult (Anzaï & Simon, 1979). The main difficulty of this problem lies in the subgoals decomposition and its ordination.

According to the appraisal theories, we anticipated that the impasse situations and subgoal achivements would be differentially appraised according to their conduciveness and obstructiveness for the goal. Therefore, these events would differentially affect the psysiological and expressive manifestations of the emotion. Specific hypotheses were tested. First the skin conductance activity was expected to be reduced in impasse situations: both spontaneous response rate and response amplitude would be lower in the impasse situations than in the subgoal achievements. Then, it was expected that in the impasse situations the negative valence of the facial expressions would be more frequent than in the subgoal achievements and contrariwise that the positive valence would be more frequent in the subgoal achievements than in the impasse situations. Secondarily, we tested the correlation between the task performance and the emotional manifestations in order to test if the results observed in previous studies relative to performance of problem-solving tasks and spontaneous skin conductance (Jutai & Hare, 1983; Lacey, Kagan, Lacey, & Moss, 1963; Munro, Dawson, Schell, & Sakei, 1987 cited in Pecchinenda & Smith, 1996) may be replicated in our study.

## 4. Method

### 4.1. *Participants and procedure*

In order to control the gender effect (Kring & Gordon, 1998), 19 female participants, mean age M = 20, 3 years (SD = 5, 26) were recruited from the University of Rouen France.

After first hearing a brief description of the study and giving informed consent, each participant was made comfortable in the laboratory room reserved for the experimental sessions. The physiological sensors were then attached to the non-dominant hand (following the recommandations of Dawson, Schell, & Filion, 2000). Once the sensors were in place, participants were asked to clear her mind and to relax by closing one's eyes for a 1-minute baseline period. Then, the participants were instructed to solve the problem and were informed that there was no alloted time to reach the solution. Participants were tested individually and videotaped. Both measures of emotion, facial expressions and spontaneous skin conductance activity, were recorded without interruption over the course of the problem-solving activity. Skin conductance activity was acquired and processed with the Biopac Student Lab Pro©.

### 4.2. *Measures*

#### 4.2.1. *Analysis of individual protocol*

As described above, a subject-by-subject analysis was carried out in ordor to identify, in each individual protocol, the impasse situations and the subgoal achievements. In order to identify the impasse situations, the behavioral signal retained in this study was the interruption of the activity without any action. Like that, an interruption of the activity above than 30 sec was considered as reflecting an impasse situation (Richard & Pointrenaud, 1988). The subgoal achievements are the objective states of the problem that have to be reached to come up to the goal. In the 5 disks-version of the Tower of Hanoi, the first subgoal is to place the biggest disk at its final place, then exactly the most little disk at its final place, and so on up to the goal.

#### 4.2.2. *Skin Conductance Activity*

Skin conductance activity was extracted for the two kinds of critical events from each analysis of individual protocol. The skin conductance activity was computed during the interruption of the activity (e.g. the impasse situations) and during a temporal window of 10 sec around a subgoal state. Two measures of skin conductance activity were computed for each event. First, the number of spontaneous responses greater than 0.05 µSiemens initiated within the critical event were counted and expressed as a rate per minute[2]. Then the amplitude of such responses was computed.

#### 4.2.3. *Facial expressions*

Facial expressiveness was videotaped without interruption over the course of the task. Two female judges, blind to the problem-solving activity, (videotapes were coded without sound and only the participants' faces were visible), independently coded the facial expressions following the FACES procedure of Kring and Sloan (1991). For each participant, the expressiveness baseline has be defined by

[2] Preliminary analyses indicated that the number of spontaneous responses and the solution time were significantly and positively correlated ($r = 0.49$; $p = .03$). Thus, we chose the number of responses per minute.

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facial expression at rest. Then, a change of the facial expression in comparison with the baseline was coded as a positive or negative facial expression. The derived measures used for further analyses were the number of positive facial expressions per minute and the negative facial expressions per minute[3].

4.2.4. *Task performances*

To test the correlation between the emotional manifestations and the task performances, we used three measures: both the solution time to solve the problem and the number of actions to reach the goal and an additional measure of the difficulty encountered by the participants: the relative time spent in impasse situations. That latter measure was computed by calculating the ratio between the amount of time spent on the interruptions and the amount of time spent on solving the problem.

## 5. Results

Two distinct sets of analyses were performed on the data. First, in the main analyses, a series of ANOVAs was performed to evaluate the effect of the appraised events of the problem-solving on the emotionnal manifestations. These analyses explicitly tested the main predictions of the study, namely that the skin conductance activity would be lower in impasse situations than in the subgoal achievements, and that the facial expressions would be differentiatly affected by the two kinds of events. All statistical tests reported are two-tailed. These main analyses were supplemented by a set of correlation analyses designed to provide additional information on the links between emotional manifestations and task performances.

### 5.1. *Emotional manifestations according to the impasses and the sub-goal achievements*

It should be noted that for these analyses only the data of twelve participants were taken into account because seven participants did not encountered impasse situations according to the rating used in this study (an interruption of the activity above than 30 sec).

5.1.1. *Skin Conductance Activity*

The effects of the appraisals of the critical events on the skin conductance activity are presented in Table 1. As can be seen, the spontaneous responses rate was significantly lower in the impasse situations than in the subgoal achievements [$t(11) = 3,99$; $p = .002$], and in a similar manner the responses amplitude was lower in the former events than in the latter [$t(11) = 2,37$; $p = .04$]

**Tableau 1**
**Means *(SD)* of spontaneous responses rate and responses amplitude according to the impasses situations and the subgoal achievements**

| | Impasse situations | Subgoal achievements |
|---|---|---|
| Spontaneous responses rate (responses/minute) | 4,85 *(1,97)* | 7,00 *(2,25)* |
| Responses amplitude | 0,35 *(0,20)* | 0,54 *(0,46)* |

[3] Preliminary analyses indicated that, whereas the number of positive facial expressions was not significantly correlated with the solution time, the number of negative facial expressions and the solution time were significantly and positively correlated ($r = 0.53$; $p = .02$). Thus, we chose the number of facial expressions per minute.

As predicted, the skin conductance activity significantly increased when successes are encountered, whereas it decreased when participants have to deal with difficulties. This result is consistent with the hypothesis that the critical and relevant appraised events in the course of a problem differentially affect the emotional manifestations. These changes in skin conductance activity support the interpretation proposed by Smith and Pecchinenda (1996) and therefore can be interpreted as reflecting the task engagement related to the appraisals of the impasse situations and sub-goal achievements.

5. 1.2. *The facial expressions*

Table 2 provides means and standard deviations of the rate of positive and negative facial expressions elicited by impasse situations and subgoal achievements. As predicted, the critical events differentially influenced the facial expressions. In the impasse situations, the rate of negative facial expressions was significantly higher than the rate of positive facial expressions [$t(11) = 2,52$; $p < .03$], and contrariwise in the subgoal achievements, the rate of positive facial expressions was significantly higher than the rate of the negative facial expressions [ $t(11) = 3,57$; $p = .004$].

**Tableau 2**
**Means *(SD)* of facial expressions according to the impasses situations and the subgoal achievements**

| | Impasse situations | Subgoal achievements |
|---|---|---|
| Number of positive facial expressions per minute | 0,6 *(0,62)* | 1,75 *(1,08)* |
| Number of negative facial expressions per minute | 1,57 *(1,15)* | 0,5 *(0,98)* |

This expected result gives support to the hypothesised relation between the facial expressions and the appraisals of the events. Appraisals of impasse situations as temporary failures elicit rather negative than positive facial expressions, and contrariwise appraisals of subgoal achievements trigger rather positive than negative facial expressions.

### 5.2. *Emotional manifestations and task performances*

A final set of correlation analyses was performed. Statistical inferences are presented in Table 3. First, concerning the skin conductance activity, spontaneous responses rate was significantly and negatively correlated with solution time and relative time spent on impasse, even when it was not significantly correlated to the number of actions. In other words, the more the participant took a long time reaching the goal and spent her time on impasse situations, the less the spontaneous responses rate was high. This result may be interpreted as reflecting task disengagement when the problem appears to be too difficult. Nevertheless, the response amplitude was not significantly correlated with any measure of the performance. Then, facial expressions, negative and positive, were not significantly correlated with performances.

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**Table 3**
**Correlations between emotional manifestations and task performances**

| | *Solution time* | *Number of actions* | *Relative time spent in impasses* |
|---|---|---|---|
| Spontaneous response rate | r = -0.67 ** | r = 0.39 | r = -0.79 *** |
| Response amplitude | r = -0.81 | r = 0.42 | r = -0.08 |
| Number of positive facial expressions per minute | R = -0.30 | R = 0.09 | R = -0.38 |
| Number of negative facial expressions per minute | R = -0.28 | R = 0.43 | R = -0.36 |

** $p < .01$. *** $p < .0001$

This set of results questions the relevance of global performances for describing the behavior in puzzle-like situations such as the Tower of Hanoi problem. Indeed, the global performances say nothing about how the problem is solved. We will develop this point in the discussion.

## 6. Discussion

### 6.1. *Emotional patterns elicited by impasses and subgoal achievements*

The results of this study offer clear evidence supporting the hypothesis that the failures and the successes encountered over the course of the solution attempt affect differentially the emotional manifestations. As predicted, in the impasse situations, the spontaneous skin conductance activity was reduced in comparison with the subgoals achievements. Both amplitude and response rate were significantly lower in the former event than in the latter. In the same way, in the impasse situations the negative valences of the facial expressions were significantly more frequent than in the subgoals achievements, and contrariwise their positive valences were significantly more frequent in the subgoals achievements than in the impasses. In other respects, these findings support the idea that skin conductance activity is a convergent measure of appraisal-related processes (Pecchinenda & Smith, 1996; Pecchinenda, 2001) and that facial expressions reflect the appraisals of the events according to their conduciveness for the goal (Kaiser & Wehrle, 2001; Scherer, 1999; Smith, 1991; Smith & Scott, 1997).

### 6.2. *Global performances task*

As described above, in order to provide additional information on the relationship between emotional manifestations and problem-solving performances, a set of correlation analyses was performed. The analyses show two main results. First, the links between performance and physiological activity depend on both measures of the performance and measures of the spontaneous skin conductance activity. Indeed, the response rate was significantly and negatively correlated with solution time and relative time spent on impasses, even when it was not significantly correlated with the number of actions. On the other hand, the response amplitude was not significantly correlated with any measure of the performance. This latter result is not consistent wih the finding reported by Pecchinenda and Smith (1996) that associated the performance with the amplitude response. This result could originate from a difference between the two experimental situations. In Pecchinenda and Smith's study, the performance was computed on the number of problems correctly solved in under a limited time, whereas in our study, because there was no alloted

time to solve the problem, all the participants ended up correctly solving the problem. Secondly, concerning the links between performance and facial expressions, no measure of the performances was significantly correlated with the facial expressions. This set of results suggest that, in puzzle-like situations such as the Tower of Hanoi problem, the measure of the global performance is less informative than the analysis of how the problem is solved. As Simon (1975) claims: «If we are to understand human problem-solving behavior, we must get a solid grip of the strategies that underlie that behavior, and we must avoid blending together in a statistical stew quite diverse problem solving whose real significance is lost in the averaging process» (p. 288). It is especially true if the goal is to study the emotion elicited by the events which are subjectively appraised as relevant for goals' solver.

### *6.3. Problem solving and emotion*

In the aggregate, these findings are consistent with the main assumption of the appraisal theories that emotion is a dynamic process resulting from the appraisals of the objects and events according to their significance for one's goals and desires. In line with this theoretical approach and previous researches (Scherer, 1984; Smith & Scott, 1997), our findings show that the appraisals lead to specific emotional response patterns. They support the assumption of the Component Process Model (Scherer, 2001; Sander, Grandjean, & Scherer 2005) that the changes in a subsystem component will elicit related changes in other subsystems.

On the other hand, these findings are a preliminary attempt to lead a better understanding of goal-oriented activities such as problem-solving because as Simon claimed (1967), it is necessary to develop a general theory of thinking and problem-solving that incorporates motivation and emotion. In this way, the present study throws new light on the problem-solving theory developed by Richard and collaborators (Richard, Poitrenaud Tijus, 1993) by taking into account emotional manifestations elicited over the course of the activity. As it is assumed by that theory, the impasses and subgoals achievements are critical steps in which the current representation has to be changed to move closer to the goal. This internal representation is supposed to change according to the evaluation of one's actions with regard to the goal achievement. When the action is evaluated as drawing nearer to the current goal, no change is expected. In return, if the result of the action is evaluated as moving away from the goal, the efficient manner to go forward is to abandon the current representation and construct a new one. In this paper, we presented the evidence that the critical events with respect to the goal are assocciated with specific emotional patterns.

Nevertheless, there is still a question with no answers. How the emotion elicited by the relevant events of the problem-solving guides the activity? In other words, it may be assumed that the experienced frustation elicited by the impasse situations would lead to different attitudes: resignation or challenge as suggested by Belalvkin (2001). Indeed, previous studies (Clément, 2006, in press) show great individual differences in managing the impasse and its going out. For some participants, the impasses are effective opportunity to learn about the situation: after these states, they change of direction of search. Even when, for others, no change is noted, and they present a kind of behavioral rigidity. These participants don't abandon the current representation: they repeat the same solution path that leads to impasse. These differences are interpreted as differences in cognitive flexibility. Thus, the intriguing and interesting question concerns the links between emotion and cognitive flexibility, and particulary how emotion influences the change of representation in the impasse situations. In other words, after the impasse situations, what are the emotional patterns of the least flexible solvers? These questions hopefully will be answered in future subject-by-subject analyses conducted after the impasse situations. In line with the appraisal theories, different emotional patterns may be anticipated according to the cognitive profils of the participants: flexible profils would be associated with emotional patterns reflecting task engagement and confidence, whereas opposite emotional patterns would accompany less flexible profils.

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