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The Skin-Conductance Component of Error Correction in a Logical Reasoning Task

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1 Damasio (1994; 1996; Damasio et al., 1994) offers eloquent support for the view that "good use of reason" depends on emotion and self-feeling. He showed that patients with VentroMedial PreFrontal cortex (VMPF) damage present severe impairment in reasoning/decision making when it comes to personal and social matters that involve risk and conflict, along with abnormal emotion and feelings, whereas their intellectual abilities are preserved. The VMPF cortex has been pointed out in several brain imaging studies to have a crucial role in emotion-cognition integration in situations with emotional saliency (Goel & Dolan, 2003; and Phan et al., 2002, for a meta-analysis of emotion activations in PET and fMRI data).

2 In our previous brain imaging studies in healthy subjects, we found that error correction in a deductive logic task elicited a right VMPF activation (Houdé, 2007; Houdé et al., 2000, 2001, 2003; Houdé & Tzourio-Mazoyer, 2003). This brings out the question of a possible implication of emotion-related processes in a pure logical reasoning task, that is, in a situation with no emotional saliency as induced by explicit risk, reinforcement, (Bechara et al., 1997) or stimulusemotional content (Goel & Dolan, 2003). In the present study, we measured Skin Conductance Responses (SCRs), an autonomic index of somatic states, i.e. of emotional changes (Damasio, 1994, 1996, 1999), which was already used recently by others authors as a reflect of subjects' feeling about their reasoning strategies in a logical task (Carbonnell et al., 2006). Applying our previous error-correction design (Houdé et al., 2000, 2001, 2003) – a kind of "neuropedagogy of reasoning" (Houdé, 2007) – we tested the hypothesis that SCRs should increase when subjects are shifting from errors to logical responses in a deductive (rule falsification) task: that is what we called "the skin-conductance component of error correction in a logical reasoning task."

3 According to deductive logic, falsification of a rule such as "If there is not a red square on the left, then there is a yellow circle on the right" requires a true antecedent and a false consequent (see Fig.1a). In the present example, placing a blue square (not a red one) on the left of a green diamond (not a yellow circle) is an example of the correct response. Yet, most subjects respond erroneously by selecting the items mentioned in the rule, a red square on the left of a yellow circle, and neglecting the logically correct response. This surprising error is well known in cognitive psychology as matching bias (Evans, 1998). Although this bias is very powerful, data obtained in our group have shown that training enables some subjects to inhibit this bias and to give logical responses in a post-training session (Houdé, 2000, 2007; Houdé et al., 2000; Moutier et al., 2002). Two types of training were used, either in logic only, or with additional emotional warnings about the reasoning error (matching bias), so as to test if the explicit emotional component could facilitate error correction. Here, we used the same training design in order to observe SCRs in subjects shifting from errors in the pre-training session to logical responses in the post-training session.

4 Forty-three right-handed subjects (19 men) participated in the study. They were between 18 and 30 years-old (mean age: 22 ± 2.7 years), and had never attended any course in reasoning or logic (mean education level: 15 ± 2). Participants were selected on the basis of their performance on the Embedded Figures Test (Oltman et al., 1985; Witkin et al., 1971), a previous study having shown that perceptual field-independent subjects (EFT score ≥ 14/18 for women and ≥ 16 for men) were more receptive to the training design than field dependent subjects (Moutier et al., 2002). All forty-three field-independent participants included in the study presented a biased reasoning behaviour during the pre-training session (i.e. matching bias responses with possibly punctual correct responses which did not prove that the subject achieved logic as mostly erroneous responses remained: > 90%). Thirteen other subjects were selected out, because they already responded logically during the pre-training session, and so could not be tested for SCRs changes when shifting from errors to logical responses. All participants gave written informed consent for their participation to this study.

5 During the pre-training and the post-training sessions, subjects had to solve the rule-falsification task described in the Introduction (96 rules in each session) without feedback and time constraint. Error correction was defined by a very clear shift, which could occur at any time during the post-training session, from a biased behaviour to a *systematic correct behaviour until the end of the session.*

6 The training session was based on asimilar logical task with different materials in order to avoid a simple instruction effect. Subjects were randomly assigned to two training conditions: (1) training in Logic (L) including explicit emotional Warnings (W) about errors (LW, n=18) or (2) the same training without these warnings, i.e. training in Logic only (L, n=18). In a third control group (n=7), we measured the test-retest effect, using the same design without training. As stated above, similarly to the pre- and post-tests, the training involved also a deductive reasoning task with conditional rules (Wason's card selection task), which triggers a matching bias (Evans, 1998; Wason, 1968). In this task, four cards (A, D, 3, and 7) with a letter on one side and a number on the other are laid out in front of the subject, who then has to state which one or ones have to be turned over to verify the rule "If there is an A on one side of a card, then there is a 3 on the other." The correct answer is A and 7 (because one must test the true-antecedent-and-false-consequent cases, since only they can falsify the rule). The matching-bias response is A

and 3. At the beginning of the training session, all 36 subjects exhibited the bias. By the end, all subjects met the learning criterion (being able to explain how to logically solve the training task) on the first unassisted attempt. The training session lasted about 20 min (see supplementary materials for an excerpt from the training instructions for each condition: LW and L).

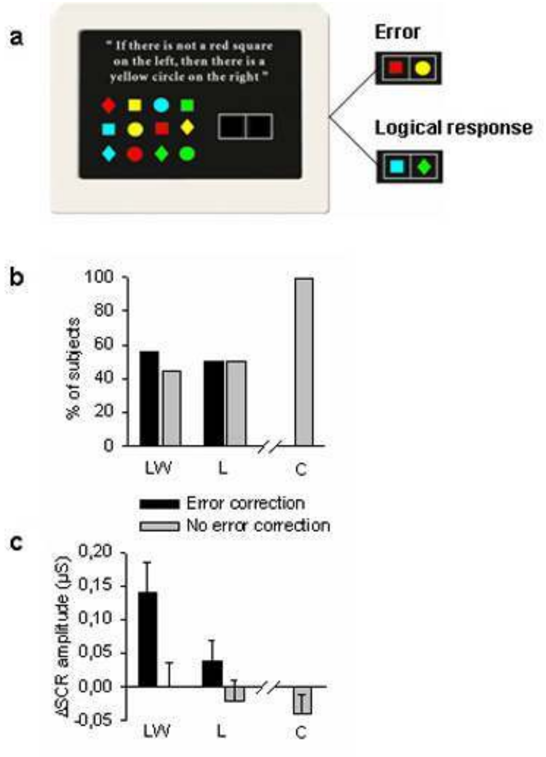
7 Skin Conductance Responses (SCRs) were continuously measured while subjects performed the rule falsification task, both before and after the training session. Ag-AgCl electrodes filled with isotonic electrolyte gel (0,5% NaCl/100 ml H_2O) were attached on the palmar surface of the median phalanges of digits II and III of the nondominant hand. The signal was processed using TSD203 transducer, GSR100C amplifier, MP100WS acquisition unit, and AcqKnowledge III software (Biopac Systems, Santa Barbara, California). Off-line filtering ($0.01<Hz<10$) was used to remove noise and SCRs triggered by movements or deep-breathing were excluded.SCRs characterized by an unambiguous response ($amplitude>0.02$ μS) were collected over ten trials out of 96 in each session (from stimulus presentation of the first of these ten trials to the subject's response to the tenth trial). In subjects who corrected the reasoning error, SCRs amplitudes values were averaged over the ten trials following error correction. In subjects who failed until the end of the post-training session (no error correction) and in control subjects, SCRs amplitudes were averaged over the ten median trials since in the group which achieved logic, error corrections occurred throughout the post-training session between the first and the 77^{th} trials (out of 96) depending on the subject. For all subjects, post-training SCRs mean amplitude was normalised taking as reference SCRs mean amplitude values over the last ten trials of the pre-training session, i.e. when the reasoning bias was automated, since SCRs amplitude did not vary much throughout the pre-test (non-significant difference between SCRs mean amplitude over the last ten and the ten median trials, $t = 1.2$, $p = 0.24$).Finally, SCRs mean amplitude over the last ten trials of the post-test was also calculated in participants who corrected the reasoning error.

8 To test whether SCRs amplitudes changed with error correction in the two training groups, we conducted a two-way ANOVA over normalized post-training SCRs mean amplitudes, with the ability to shift to logic during the post-training session (Shifting: error correction or no error correction) and the type of training (Training: LW or L) as two between-participants factors. In addition, to test whether such a change lasted during the post-test or if SCRs mean amplitudes returned to baseline level, a paired *t* test was performed in successful subjects to compare SCRs mean amplitudes at the end of the post-training session and at the end of the pre-training session.

9 Regardless of the type of training (LW or L) received, subjects corrected equally well their reasoning errors in the rule falsification task in the post-training session (56% of the subjects after LW training and 50% after L training; none in the control group) (see Figure 1b). Remember that error correction was assessed by a clear shift from >90% of errors (during 96 rules) in the pre-training session to systematic correct reasoning at any time of the post-training session (between the first and the 77th rules out of 96) and until the end of this session. Thus, in our data, the presence of explicit emotional Warnings (W) about errors during the training session was not the key factor of shifting from errors to logical responses.

10 Remarkably, regardless of the type of training received, the SCRs mean amplitude between the pre- and post-training sessions significantly increased only in subjects who shifted from errors to logical responses, as compared to those who kept exhibiting the

reasoning error (Figure1cand Table 1; two-way ANOVA: Shifting effect, $F(1,32)=7.4$, $p<0.01$; Training effect, $F(1,32)=2.8$, $p=0.1$; interaction, $F(1,32)=1.2$, $p=0.28$). In subjects who corrected their reasoning error, SCRs mean amplitude at the end of the post-training session returned to baseline level (mean SCRs amplitude of the last ten trials of the pre-test; see Table 1; paired *t* test: $t=0.6$, $p=0.5$). Thus, it clearly appears that the SCR increase was related to the time when the subjects shifted from errors to logical responses and did not last after they had automated the logical strategy. Considering also that in the control group, with no training and no error correction, the SCRs mean amplitude gradually decreased during the pre- and post-test sessions, the increase found in the training conditions can not be assigned to environmental factors.



11 **Figure 1**. Skin conductance responses increase with error correction in a deductive logic task. **(a)** Subjects were visually presented with 12 coloured geometric shapes displayed randomly on a computer screen and had to falsify a conditional (if-then) rule. They responded with the mouse by putting two shapes in a two-part box drawn on the screen, one on the left for the antecedent (if) and the other on the right for the consequent (then). One second after the subject's response, the computer displayed a new stimulus. In each session, before (pre-test) and after (post-test) training, the subjects solved 96 rules without feedback. **(b).** Percent of subjects who corrected, or did not correct, their reasoning error during the post-test session as a function of the training condition (training in Logic (L) with explicit Warnings (W) about errors, training in Logic only; and control (C), i.e., no training). **(c).** Skin conductance response (SCR) variations: post-test minus pre-test SCR mean amplitudes (± s.e.m.), as a function of training condition (LW, L, or C) and reasoning performance (error correction or no error correction).

12 **Table 1.** Mean SCRs amplitude values over 10 trials at different moments of the experiment as a function of the training condition (training in Logic with explicit Warnings about errors (LW), training in Logic only (L), and control condition (C) without training), and of reasoning performance (error correction or no error correction).

		Mean SCRs amplitude over 10 trials ± s.e.m.		
		Last 10 trials of the pre-test	10 trials after error correction or 10 median trials of the post-test	Last 10 trials of the post-test
Group of subjects	Error correction after LW training (N = 10)	**0.06** ± 0.02	**0.2** ± 0.04	**0.09** ± 0.03
	No error correction after LW training (N = 8)	**0.1** ± 0.04	**0.1** ± 0.03	**0.14** ± 0.05
	Error correction after L training (N = 9)	**0.08** ± 0.02	**0.12** ± 0.03	**0.07** ± 0.02
	No error correction after L training (N = 9)	**0.09** ± 0.04	**0.07** ± 0.02	**0.07** ± 0.03
	No error correction in the Control condition (N = 7)	**0.14** ± 0.03	**0.1** ± 0.03	**0.1** ± 0.04

13 These results confirm that error correction during a pure deductive logic task, devoid of real risk, reinforcement, personal or social matters, or of any other *salient* emotional content (and here, regardless of the presence or absence of *explicit* emotional warnings during the training session), involves not only a “cold” (logical) and cerebral (Houdé et al., 2000) kind of cognition, but also *implicit* somatic states. Nevertheless, the nature of the somatic states involved here remains to be explored in future research. The SCRs increase associated with error correction in the post-training session may reflect the reactivation of somatic states previously evoked during the training in a similar reasoning task. Indeed, the different responses labelled either “right” or “wrong” during the two training conditions may have been somatically encoded as “good” or “bad” choices (see Supplementary materials: training instructions). During the post-training session where the task to perform relies on similar choices, these somatic states may have guided the subject on the track of logic, alerting him to the badness of the matching bias. This process seems to have acted overtly in some subjects who corrected the reasoning error in the post-test session as they reported a conscious feeling of being wrong (in a post-experimental verbal debriefing, to the question: “Were you aware of committing an error when using the first strategy?”).

14 The SCRs increase associated with subjects’ error correction could also be accounted for by their mental effort to inhibit their prepotent erroneous response, i.e. the matching bias (Dempster & Brainerd, 1995; Houdé, 2000, 2007; Houdé et al., 2000; Houdé & Tzourio-Mazoyer, 2003). Mental effort, as underlined by Naccache et al. (2005), is not usually considered as an emotional feeling, yet it belongs to the wider class of feelings defined as the conscious appraisal of one’s own state (Damasio, 1999). Both the alert process and mental effort may have helped the subjects get it right in the post-training session.

15 Finally, SCRs increase might also be related to a more primary “fear-like” emotion that the new strategy used may be wrong, which, however, was not consciously reported by subjects who corrected the reasoning error.

16 The right VMPF cortex activation that we previously found to be involved in error correction within our logical reasoning design (Houdé et al., 2001; Houdé, 2007; Houdé & Tzourio-Mazoyer, 2003) has also been related to afferent representation of SCR events by other authors (Critchley et al., 2000). It is considered as a zone of integration of cognitive and somatic information, providing adaptive responses (Critchley et al., 2000; Damasio, 1994, 1996, 2003). Hence, it would be interesting in future research to combine brain imaging techniques and psychophysiological recording of skin conductance responses

within our logical reasoning design, in order to investigate the possible link between error correction ability, SCR events, and right VMPC activation.

17 Below is an excerpt from the LW training instructions (warnings are shown in italics): “In this problem, the source of the error lies in a habit we all have of concentrating on cards with the letter or number mentioned in the rule and not paying attention to the other cards. [...] The goal here is to not fall into the trap of the two cards A and 3 mentioned in the rule and to consider all of the cards, A, D, 3, 7, one by one, by imagining the number or the letter it might have on the back to see whether these cards can make the rule false ... To help you understand, let's consider the different answers and eliminate the wrong ones – the ones that make you fall into the trap – to find the right answer.” Then, the subject was shown a board on which the response repertoire was depicted as a box. Different answers (A, A-3, and A-7) were represented on three cards, which could be slid onto the response repertoire. The answer cards were of different colors, depending on whether the answer was wrong (A, A-3) or right (A-7). The experimenter said to the subject: “In the box you see here, we're going to put the different answers written on these cards, while clearly separating the wrong answers, which make you fall into the trap – we’ll put them under a transparent hatched area – and the right answer. Let's start with answer A. [...]” (Complete logical instructions for answers A, A-3, and A-7 are available upon request). The procedure of the L training was the same as the above procedure, but without the warning elements in italics.

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NOTES

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ABSTRACTS

Skin Conductance Responses (SCRs) were measured in a deductive logic task performed twice by the same subjects, first making reasoning errors and then, after training, providing logical responses or making errors again, depending on the subject. SCRs increased between the two sessions and were significantly higher in the subjects who corrected their reasoning errors than in those that did not, showing the strong interplay between logical reasoning and indices of somatic states involved in emotion. This fits well with the results of previous brain imaging studies from our group showing that access to deductive logic depends on a right ventromedial prefrontal area involved in SCRs afferent representation and emotion-cognition integration.

La Réponse ÉlectroDermale (RED) a été mesurée à deux reprises chez les mêmes sujets qui réalisaient une tâche de logique déductive, d'abord en commettant une erreur de raisonnement et ensuite, après un apprentissage, soit en répondant correctement, soit en persévérant dans l'erreur selon les sujets. La RED s'est accrue entre les deux sessions et était significativement plus importante chez les sujets qui corrigeaient leur erreur initiale de raisonnement que chez les autres, révélant la forte interconnexion entre le raisonnement logique et les indices d'états somatiques impliqués dans l'émotion. Cela corrobore les résultats d'études antérieures d'imagerie cérébrale réalisées dans notre groupe et indiquant que l'accès à la logique déductive dépend du cortex préfrontal ventromédian droit dont on connaît l'implication dans la représentation afférente de la RED et dans l'intégration émotion-cognition.

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Keywords: Skin conductance responses, Logical reasoning, Error correction, Emotion-cognition integration.

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