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The architecture of cognitive control in schizophrenia

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Executive dysfunctions have long been considered a common feature of schizophrenia. However, due to their extreme heterogeneity, it is not clear whether these impairments take place at a particular level of executive functioning or non-specifically affect various aspects of behavioural control. To answer this question, we used an experimental paradigm based upon a multistage model of prefrontal executive function. This model postulates that cognitive control is organized in three hierarchically ordered control processes, operating with respect to the *perceptual context* (sensory and contextual controls) or the *temporal episode* in which the person is acting (episodic control). Twenty-four patients with schizophrenia and 24 non-psychiatric controls participated in two distinct experiments designed to separately assess each of these three levels of control. The results indicate that both sensory and episodic dimensions of cognitive control were spared in schizophrenic patients, but that they showed great difficulty in contextual conditions, as the selection of the appropriate response among competitive ones required taking into account information related to perceptual context. Contextual control can be considered as a set of executive processes mediating the hierarchical organization of behaviour. Patients' deficit in cognitive control therefore reflects a specific problem in the hierarchical control of action, leading to the selection of inappropriate behavioural representations for ongoing action plans. We also showed that this impairment was a good predictor of disorganization syndrome scores, suggesting that these clinical manifestations might result from a deficit in the combination or selection of hierarchically organized action representations.

Keywords: cognitive control; cascade model; schizophrenia; context processing; disorganization syndrome

Abbreviations: EPs = error percentages; RTs = reaction times; SR = stimulus-response; WAIS = Wechsler Adult Intelligence Scale

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Introduction

Executive dysfunctions have long been considered a common feature of schizophrenia (Velligan and Bow-Thomas, 1999). However, despite their pervasiveness, these high-level cognitive disorders have proved highly resistant to systematization. Particularly noticeable is their extreme variability among patients in terms of both severity and nature (Shallice *et al*., 1991), raising the question of their specificity regarding schizophrenia itself (O'Leary *et al*., 2000) as well as the specificity of the tasks developed to assess them (Lezak, 1993; Axelrod *et al*., 1996).

One way to solve this ambiguity is to tackle the problem at a more fine-grained level of cognitive functioning. Executive functions are considered to be a product of various processes (e.g. information selection, inhibition, maintenance, etc.), the coordination of which is assumed to be achieved by a mechanism called cognitive control (Funahashi, 2001). Our claim is that executive function deficits in schizophrenia could be accounted for by a specific impairment of this control mechanism.

Despite notable advances, the executive processes and their functional architecture remain poorly specified (Godefroy *et al*., 1999). Recently, Koechlin *et al*. (2003) addressed this question by proposing an original model of cognitive control, based on an extensive investigation of prefrontal function and organization. By demonstrating that the frontal cortex is functionally organized as a *cascade* of control processes, the authors showed that cognitive

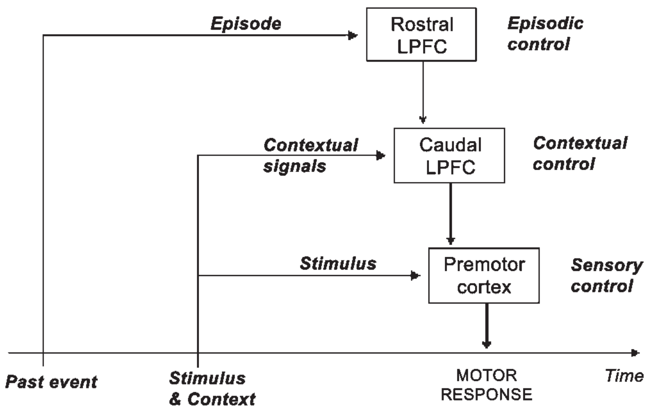

Fig. 1 Model of cognitive control by Koechlin *et al*. (2003). The multistage organization of information processing includes a SENSORY control level involved in selecting the motor responses that are the most appropriate to stimuli that occur. This control is subserved by the lateral premotor regions. The CONTEXTUAL control level is involved in selecting SR associations according to *contextual* signals accompanying stimuli occurrences. This control is subserved by the caudal part of the lateral prefrontal cortex. The EPISODIC control level is involved in selecting task-sets or consistent sets of SR associations evoked in the same context according to the *temporal episode* in which stimuli occur; that is, according to events that previously occurred or to ongoing internal goals. This control is subserved by the rostral part of the lateral prefrontal cortex. Courtesy of Koechlin *et al*. (2003).

control involves at least three levels of processing implemented in distinct frontal regions. These control processes operate with respect to the *perceptual context* (contextual control) or the *temporal episode* in which the person is acting (episodic control) (Koechlin *et al*., 2003). The model generalizes the classical theory of executive control from Baddeley and Hitch (1974), based on a central executive system controlling multiple maintenance slave systems, to a multistage architecture, where each level of the frontal hierarchy mediates the processing of a distinct signal (sensory, contextual or episodic signals) involved in controlling the selection of appropriate stimulus-response (SR) associations. Furthermore, the cascading nature of this model is derived from the idea that processing carried out at each level of this hierarchy is constantly informed by the processing driven by progressively higher levels, thus, giving rise to a *cascade* of top-down, successive controls (Fig. 1).

In addition to identifying different control processes associated with distinct types of signal, this model also takes into account variations in the demands of these controls. These demands vary as a function of the information (in terms of information theory) (Shannon, 1948) conveyed by the control signals that are required for selecting appropriate representations for action. The cascading model of Koechlin *et al*. (2003) thus proves appropriate, not only for identifying which processes of the control hierarchy might be specifically dysfunctional in schizophrenia, but also for evaluating the influence of the varying demands of these controls on patients' performance.

We adapted the experimental paradigm of Koechlin *et al*. (2003) in order to evaluate the performance of patients with schizophrenia, and healthy participants, in visuomotor association tasks modelling sensory, contextual and episodic controls. We expected impaired cognitive control to affect specific levels of the hierarchy. As it has been shown that patients correctly use a rule to associate a stimulus with a response (Posada and Franck, 2002), we predicted that the level of sensory control would be spared. In contrast, contextual and/or episodic controls could be more specifically impaired because they require higher temporal integration, a deficit which might characterize schizophrenia (Jones *et al*., 1991; Cohen and Servan-Schreiber, 1992; Gras-Vincendon *et al*., 1994). Based upon the many reports of an association between executive dysfunction and disorganized thoughts and behaviours in schizophrenia (Mahurin *et al*., 1998; Kravariti *et al*., 2005), we also looked at whether patients' performance in cognitive control was associated with the severity of disorganization symptoms.

Methods

Participants

Twenty-four patients with schizophrenia (9 females, 15 males; mean age: 37.33 years, SD: 9.7) and 24 healthy participants (9 females, 15 males, mean age: 36 years, SD: 12) participated in the study. Patients recruited fulfilled DSM-IV (American Psychiatric Association, 1994) criteria of schizophrenia, with no other psychiatric diagnosis on DSM-IV Axis I. All patients were receiving antipsychotic medication (principally olanzapine, risperidone and aripiprazole) and were clinically stable at the time of testing (duration of illness: mean: 9.4 years, SD: 6.3). Negative and positive symptoms were evaluated with the SANS (mean: 40.3, SD: 15.4) (Andreasen, 1983) and the SAPS (mean: 41.2, SD: 19) (Andreasen, 1984). A disorganization score (mean: 26.95, SD: 11.97) was also computed by summing the following subscores: bizarre behaviour, positive formal thought disorder, alogia and inappropriate affect. Intellectual efficiency was assessed in the schizophrenia group by two trained neuropsychologists using the Wechsler Adult Intelligence Scale (WAIS-third edition; Wechsler, 1997). The mean 'Total IQ' reported for the schizophrenia sample (mean: 92.2, SD: 8.57) did not differ from the normal range.

Controls subjects were matched with patients for sex, age, handedness (patients: mean = 0.74, SD = 0.51, controls: mean = 0.79, SD = 0.46; Oldfield, 1971) and years of education. None of them reported psychiatric problems.

For both groups, exclusion criteria included dyschromatopsy, history of neurological illness or trauma, alcohol or drug dependence according to DSM-IV criteria, analphabetism and age older than 60 years. All participants reported normal or corrected-to-normal visual acuity. After complete description of the study to the subjects, written informed consent was obtained. This research was approved by the local Ethical Committee.

Task

The study consisted of two behavioural experiments that were designed to separately vary the demands of sensory and episodic controls (MOTOR experiment) and contextual and episodic

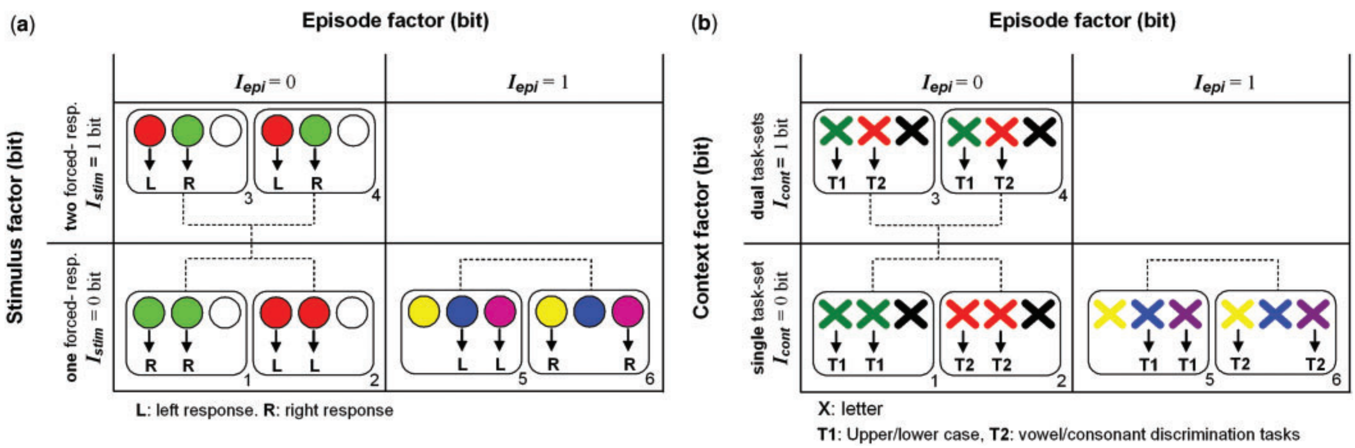

Fig. 2 Experimental designs. Rounded boxes represent behavioural episodes (numbered from 1 to 6) with related stimuli and instructions. (**a**) MOTOR experiment: episodes formed three distinct experimental conditions crossing the Episode factor with the Stimulus factor. In this experiment, stimuli were coloured discs. Subjects ignored distractor stimuli or responded by pressing the left (L) or right (R) response button. Dashed lines connect episodes involving congruent stimulus-response associations. (**b**) TASK experiment: episodes formed three distinct experimental conditions crossing the Episode factor with the Context factor. In that experiment, stimuli were letters (represented by the symbol X) and contextual signals were colours of letters. Letters were pseudorandomly chosen from the set **{**A, E, I, O, U, Y, a, e, i, o, u, y, B, D, G, K, R, T, b, d, g, k, r, t**}**. Depending on the contextual signals, subjects ignored letters (no arrow) or performed either a lower/upper case (T1) or a consonant/vowel (T2) discrimination task on letters. Dashed lines connect episodes involving congruent associations between contextual signals and task-sets.

controls (TASK experiment). For each experiment, participants performed a visuomotor association task in which they responded to a series of successively presented visual stimuli (coloured discs or letters) by pressing left or right hand-held response buttons. Each experiment was administered using a 6×6 Latin-square block design consisting of six different stimuli, each presented in six separate blocks (episodes). Each block included a series of 12 stimuli presentations (duration: 500 ms; onset asynchrony: 3500 ms), preceded by an instruction cue (episodic signal) lasting 3200 ms. Subjects were required to respond as quickly and accurately as possible.

The stimuli were presented on a computer monitor (16″) and a head-fixation device was used to both control the distance separating the subject from the test monitor (60 cm) and to minimize head movements that might influence reaction times. The MOTOR and TASK experiments were conducted on two successive days. Their order of presentation was counterbalanced across participants, as was the order of block presentation within each experiment.

Prior to running the experiment, participants were trained in order to avoid possible biases due to learning effects during the test session. The stimuli were presented using the EXPE6 software (http://www.ehess.fr/centres/lscp/expe).

The demands of sensory, contextual and episodic control were separately varied across the experiments. These variations were quantified according to the computational model from Koechlin *et al.* (2003), based on Shannon's information theory (Shannon, 1948). Details concerning the calculation of information values for the different signals are provided in the original study by Koechlin *et al.* (2003).

In the MOTOR experiment, subjects had to respond to coloured discs by pressing the left (L) or right (R) response button and to ignore distractor stimuli. The demands of sensory control were conveyed by the stimulus indicating the response to be chosen and varied across blocks. These demands were expressed in 'binary digits' (bits) and represented discrete values quantifying the amount of information subjects had to control during the task [noted (0) or (1)] (Koechlin *et al.*, 2003). Sensory information was of 0 bit ($I_{sti} = 0$ bit) for blocks with one forced response and of 1 bit for blocks with two forced-responses ($I_{sti} = 1$ bit). The ratio of left versus right responses was equal to 1. In this experiment, no contextual signal was used, so that no contextual control occurred (Fig. 2a).

In the TASK experiment, subjects had to respond to coloured letters. Depending upon the colour of the letter, subjects had to perform a lower/upper case (T1), or a consonant/vowel (T2) discrimination task (using the left and right response buttons) or had to ignore the stimuli. The demand of contextual control was conveyed by the colour of the stimulus about a task-set and varied across blocks. Contextual information was of 0 bit for blocks involving a single task-set ($I_{cont} = 0$ bit) and of 1 bit for blocks involving a dual-task-set ($I_{cont} = 1$ bit). The ratio of trials associated with task-set T1 versus task-set T2 was equal to 1. Letters were pseudorandomly chosen so that in each block the ratio of left versus right responses and the ratio of congruent versus incongruent letters (same versus different responses for T1 and T2) were equal to 1. In that experiment, sensory control was maintained constant across the blocks (Fig. 2b).

For each experiment, the demand of episodic control (e.g. episodic information) was conveyed by instruction cues indicating which task-set to perform, given other signals (sensory or contextual signals). Episodic information was required for selecting appropriate SR associations (MOTOR experiment) or appropriate task-sets (TASK experiment) and varied parametrically across blocks (from $I_{epi} = 0$ to 1 bit) (Fig. 2). Proportions of two successive trials including identical stimuli or identical contextual signals were also maintained constant across blocks. In each block, sequences of stimuli were pseudorandomized so that the proportion of distractors was equal to 33%.

Description of the experimental blocks for experiment 1

Block #1: Discs were either green or white. White discs were distractors and subjects had to respond to green discs by pressing the right button (one forced-response episode, Istim[0]*Iepi[0]).
Block #2: Discs were either red or white. White discs were distractors and subjects had to respond to red discs by pressing the left button (one forced-response episode, Istim[0]*Iepi[0]).
Blocks #3 and #4: Discs were either green, red or white. Subjects had to respond to stimuli as in blocks #1 and #2 (two forced-response episodes, Istim[1]*Iepi[0]).
Blocks #5: Discs were either yellow, blue or cyan. Yellow discs were distractors and subjects had to respond to blue and cyan discs by pressing the left button (one forced-response episode, Istim[0]*Iepi[1]).
Blocks #6: Discs were either yellow, blue or cyan. Blue discs were distractors and subjects had to respond to yellow and cyan discs by pressing the right button (one forced-response episode, Istim[0]*Iepi[1]).

Description of the experimental blocks for experiment 2

Block #1: Contextual signals were either green or white. White signals indicated subjects should ignore the letter. Green signals indicated subjects should perform task T1 (single task-set episode, Icont[0]*Iepi[0]).
Block #2: Contextual signals were either red or white. White signals indicated subjects should ignore the letter. Red signals indicated subjects should perform task T2 (single task-set episode, Icont[0]*Iepi[0]).
Blocks #3 and #4: Contextual signals were either green, red or white. Subjects had to respond to letters as in blocks #1 and #2 (dual task-set episode, Icont[1]*Iepi[0]).
Blocks #5: Contextual signals were either yellow, blue or cyan. Yellow signals indicated subjects should ignore letters. Blue and cyan signals indicated subjects should perform task T2 (single task-set episode, Icont[0]*Iepi[1]).
Blocks #6: Contextual signals were either yellow, blue or cyan. Blue signals indicated subjects should ignore letters. Yellow and cyan signals indicated subjects should perform task T1 (single task-set episode, Icont[0]*Iepi[1]).

Data analyses

Reaction times (RTs) for correct responses and error percentages (EPs) were recorded and analysed using the software Statistica7. In each experiment, the six blocks formed three distinct experimental conditions crossing the episode factor (instruction cue) with either the Stimulus (MOTOR experiment) or the Context factor (TASK experiment). In the MOTOR experiment, the Stimulus factor ($\boldsymbol{I}_{\mathbf{stim}}$) contrasted one-forced response and two-forced responses episodes. In the TASK experiment, the Context factor ($\boldsymbol{I}_{\mathbf{cont}}$) contrasted single-task-set and dual-task-set episodes. Finally, in both experiments, the Episode factor ($\boldsymbol{I}_{\mathbf{epi}}$) contrasted episodes with $\boldsymbol{I}_{\mathbf{epi}}=0$ and episodes with $\boldsymbol{I}_{\mathbf{epi}}=1$. For the sake of clarity, the Episode factor was termed EpiMotor ($\boldsymbol{I}_{\mathbf{epiM}}$) in the MOTOR experiment and EpiTask ($\boldsymbol{I}_{\mathbf{epiT}}$) in the TASK experiment.

For each experiment, we computed a 2 (group) × 2 (control factor 1) × 2 (control factor 2) repeated-measures ANOVA on both RT and EP data. Analyses were made with group (schizophrenic patients versus controls) as a between-subjects factor, Episode ($\boldsymbol{I}_{\mathbf{epi}}=0$ versus $\boldsymbol{I}_{\mathbf{epi}}=1$) as a within-subjects factor and Stimulus ($\boldsymbol{I}_{\mathbf{stim}}=0$ versus $\boldsymbol{I}_{\mathbf{stim}}=1$) and Context ($\boldsymbol{I}_{\mathbf{cont}}=0$ versus $\boldsymbol{I}_{\mathbf{cont}}=1$) as within-subjects factors for the MOTOR and TASK experiments, respectively. *Post hoc* Fisher tests were performed to identify differences. Whenever the variance structure did not conform to the requirements for parametric analyses, logarithmic transformations were used to obtain the required conformity.

Regression analyses

Regression analyses were conducted to evaluate the influence of patients' cognitive performance on their clinical scores. Independent analyses were made with the disorganization score, its subscores, the SANS and SAPS scores as dependent variables and cognitive performances as explanatory factors. Cognitive scores were computed by subtracting EPs in conditions in which $I=1$ from conditions where $I=0$, while maintaining the other factor constant. Three scores were computed: a sensory score ($\mathrm{Score}_{\mathrm{sti}}$), a contextual score ($\mathrm{Score}_{\mathrm{con}}$) and an episodic score ($\mathrm{Score}_{\mathrm{epi}}$). For each clinical score, we conducted regression analyses using the different cognitive scores independently (simple linear regressions) or their transformed values (simple non-linear regressions with logarithmic, polynomial or exponential transformations) or a linear combination of two cognitive scores (multiple linear regressions). Models with the highest adjusted R-squared (R^2) and a P-value $\leqslant 0.05$ are reported.

Results

Reaction times

ANOVAs performed on the transformed reaction times first confirmed the results obtained by Koechlin *et al.* (2003), showing significant effects of the Stimulus, Context and Episode factors [all effects: $F(1,138)$, $P<0.0001$]. Reaction times were slower as the demands of cognitive controls increased (from $I=0$ to 1 bit). A group effect was also observed with patients being significantly slower than controls [both experiments: $F(1,138)$, $P<0.0001$]. There were, however, no interaction effects between group and cognitive factors indicating that the generalized slowdown of patients' RTs was independent of the condition (Fig. 3).

Error percentages

Participants' error percentages were found to significantly increase as the Stimulus, Context and Episode factors varied from 0 to 1 bit [all effects: $F(1,138)$, $P<0.0001$]. EPs were also higher in patients compared to controls, as revealed by a significant group effect [both experiments: $F(1,138)$, $P<.0001$]. Significant interactions between the Group factor and the Cognitive factors were only observed in the TASK experiment for both the Context and the Episodic factors [interactions: $F(1,138)=11.97$, $P<0.001$; $F(1,138)=5.41$, $P<0.05$]. Although patients performed better than chance (one-tailed t-tests, all $t<-25$, df = 24, $P<0.001$), the percentage of errors they made was substantially higher as episodic and contextual information

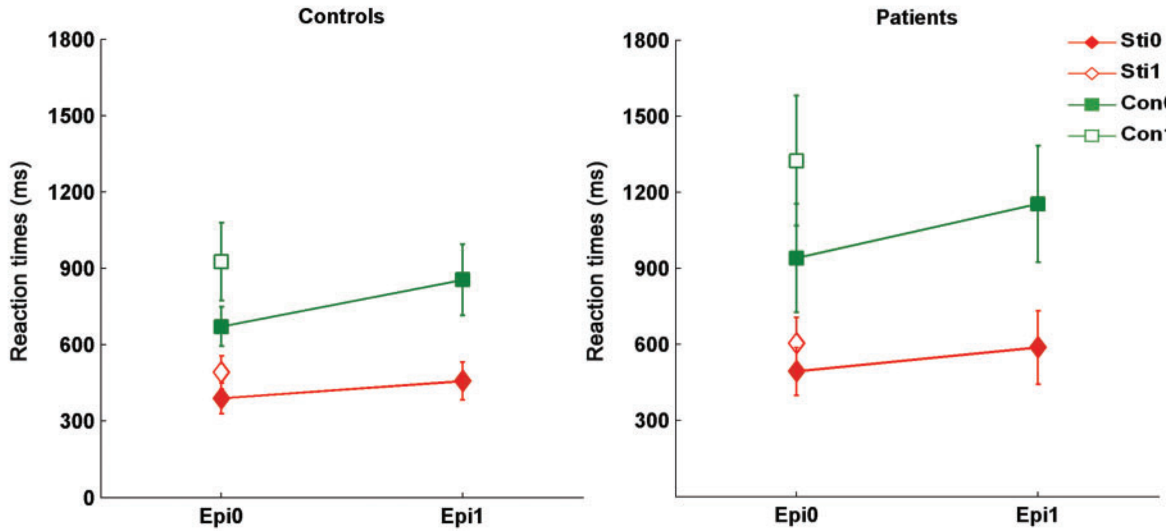

Fig. 3 Reaction times to stimuli (mean ± SD patients and controls averaged across correct responses). Reaction times are plotted for the different information values of control signals in the MOTOR (red) and the TASK (green) experiments.

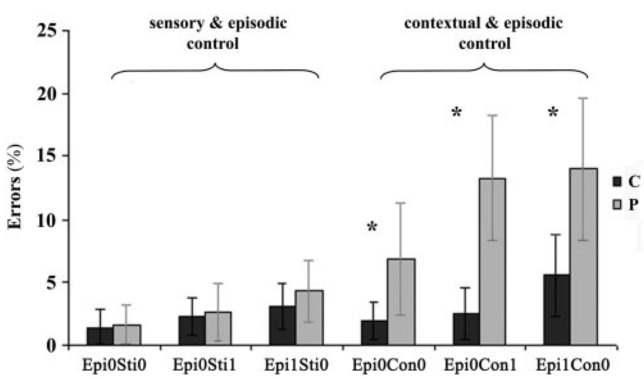

Fig. 4 Percentages of errors (mean ± SD) in patients (grey) and controls (black). The percentages are plotted for the different information values of control signals. $^{*}P < 0.001$.

increased ($P = 0.0045$), whereas controls performed equally in the different conditions ($P > 0.05$) (Fig. 4). Patients' performance, however, did not deteriorate differently from controls' as the demands of sensory and episodic controls increased in the MOTOR experiment (both interactions Group*Epi: $P > 0.05$) indicating that varying the amount of information conveyed by sensory and episodic signals did not increase patients' error percentages more than in the control group. Finally, comparing EPs in the first and second half of blocks within each group, we found that no effect significantly varied over episodes, (two-tailed t-tests, all $t < 1.9$, $\mathrm{df} = 24$, $P > 0.05$) indicating that there was no learning effect within the block for either patients or control subjects.

Regression analyses

Impairments associated with an increased demand of contextual control (i.e. contextual score) significantly predicted the disorganization score ($R^2 = 0.21$, $P < 0.05$) and in particular, its formal thought disorders subscore ($R^2 = 0.21$, $P < .05$) (Fig. 5). The more patients were disorganized or specifically exhibited thought disorders, the higher their EPs when demands of contextual control varied from 0 to 1 bit. On the other hand, SANS and SAPS scores were not found to be predicted by any cognitive performance nor by any combination of cognitive performances. This was also true when the cognitive performance scores were transformed.

Discussion

In a previous study, Koechlin *et al.* (2003) showed that cognitive control is structured on three separate hierarchically organized levels, the corresponding signals of which are treated in turn (sensory > contextual > episodic), thus permitting the selection of the appropriate response given a specific stimulus. In that multistage model, the processing carried out at each level of the control hierarchy is constantly informed by the processing driven by progressively higher levels, giving rise to a *cascade* of top–down, successive influences along the antero–posterior frontal axis. As suggested in introduction, the Koechlin *et al.*' s model is broadly derived from classical theories of executive control (Baddeley and Hitch, 1974) and of the prefrontal cortex organization—in particular those that focus on top–down attentional control, such as the top–down attentional supervisor from Shallice or Passingham's model of 'attention to action' (Passingham, 1993; Shallice, 1998; see also Koechlin and Summerfield, 2007).

Using a paradigm based on this cascade model, we selectively assessed cognitive control in a group of patients with schizophrenia, by evaluating the contributions of each level (sensory, contextual, episodic levels) of the hierarchy to a visuomotor association task. We first showed that the

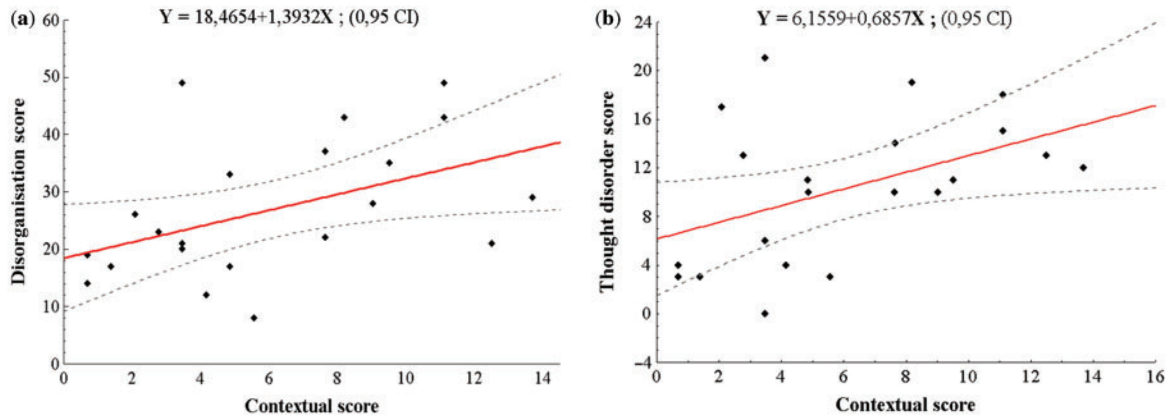

Fig. 5 The linear regression lines (and their respective equations) derived from the linear regressions analyses between patients' contextual score (explanatory factor) and their disorganization score (**a**) and thought disorder score (**b**) are shown in red. The 95% confidence interval (CI) around the regression lines are shown in grey.

architecture of cognitive control in schizophrenic patients was roughly similar to that of comparison participants, with a multistage, cascading organization of information processing. Indeed, as in healthy participants, both patients' RTs and EPs were found to increase when processes of control involved progressively higher level stages (e.g. sensory > contextual > episodic control), just as they performed worse as the information conveyed by the control signals increased (e.g. from $I = 0$ to 1 bit).

However, despite a similar pattern of increased latencies in both groups, patients' EPs differed from healthy participants with respect to both the level and the demand of cognitive control. Interestingly, this perturbation appeared under certain conditions only. Indeed, patients with schizophrenia were found to perform as well as healthy subjects in tasks requiring sensory and episodic control, whereas they showed great difficulty with tasks requiring the control of contextual cues.

In the MOTOR experiment, both the episodic information—which pre-activated a set of visuomotor associations congruent with the ongoing episode—and the sensory information—which ensured the selection of a particular response among that set—were correctly processed by patients. Furthermore, patients were influenced in the same way as comparison participants by the varying demands of sensory and episodic controls (Epi0Sti0 > Epi0Sti1 and Epi0Sti0 > Epi1Sti0) since neither the main effect of condition nor the interactions between group and conditions were significant. Taken together, these observations confirm previous results obtained by Posada and Franck (2002) who, using a visuomotor association task, showed that patients with schizophrenia correctly used a rule to associate a colour with a response.

On the other hand, patients' performance significantly differed from healthy participants when control of contextual cues was specifically required in order to associate a response with a stimulus (TASK experiment). This impaired performance could not result from variations in memory load (i.e. from maintaining instructions related to cues over subsequent episodes) because these variations were larger in the two-forced versus single-forced conditions, yet patients performed equally well in both conditions. Error patterns also cannot be explained by patients having forgotten the rules, since these were given to subjects prior to each episode, nor by difficulties in maintaining a task-set in working memory within an episode because EPs did not vary within episodes. Finally, regarding the specificity of the deficit, the poor performance of patients in contextual conditions is unlikely to be attributed to the difficulty of the task. Indeed, healthy subjects were found to perform at comparable levels across the MOTOR (episodic and sensory) and TASK (episodic and contextual) experiments, suggesting an equal discriminating power between both tasks (Chapman and Chapman, 1973*b*, 2001). This observation is consistent with a specific deficit in context processing where, all else being equal, patients' performances significantly decreased as the task required, specifically, controlling contextual information, whereas those of healthy subjects remained constant.

Context processing impairments have long been considered as a core feature of schizophrenia (Cohen and Servan-Schreiber, 1992) and numerous studies confirm the extent of this deficit in the disease (Stratta *et al.*, 1998; Braver and Cohen, 1999; Stratta *et al.*, 2000; Elvevag *et al.*, 2000; Barch *et al.*, 2003). Patients with schizophrenia tend to preferentially select the most frequent meaning of an ambiguous word and conversely, to neglect information concerning the immediate context, even when this is crucial for selecting a less dominant but more relevant meaning of a word (Cohen and Servan-Schreiber, 1992). Similarly, increased interference effects created by the higher conflict between irrelevant words and relevant contextual information like colour in the Stroop task, is well-documented in patients with schizophrenia (Perlstein *et al.*, 1998, for a review).

As pointed out by Park and collaborators (Park *et al.*, 2003; see also Hemsley and Phil, 2005), context proves to be a highly composite construct, with various dimensions referring to separate processes which may be differentially impaired—some dimensions being possibly intact, while some others may not be. The context multidimensionality may thus render its operationalization subject to some confusion, hence the importance of a detailed and rigorous definition as to what this construct refers to. In a broad sense, context can be defined as an internal representation of any task-relevant information that can be used to mediate an appropriate behavioural response (Braver and Cohen, 1999). Under this account, context may include various things like the prior stimulus, the results of processing a sequence, the task instructions ('episodic context') and can even be extended to physical features of the stimulus itself ('perceptual context': location, size, colour...) (Park *et al.*, 2003). In the light of our results, we propose that not all aspects of this information of context are dysfunctional in schizophrenia. In particular, the episodic dimension of this information could be spared in schizophrenic patients, as suggested by their good performance on the MOTOR experiment where the selection of the appropriate response required correctly and continuously processing episodic context information (task instructions). On the other hand, patients were found to perform worse in conditions in which the selection of the appropriate task-set required taking into account the perceptual, immediate context associated with the target stimulus (the letters' colour). In such tasks, patients' poor performance revealed a default in their perceptual context processing required to select the appropriate task-set among competitive ones (lower/upper case or consonant/vowel discrimination).

As revealed by Koechlin *et al.*'s model (Koechlin *et al.*, 2003), contextual control of action is implemented within the caudal part of the lateral prefrontal cortex (cPF) which mostly overlaps with the well-known Broca's area (BA 44, 45). Recently, the contribution of this region to behavioural control was clarified, when it was shown to be involved in the hierarchical organization of behaviour (Koechlin and Jubault, 2006). Broca's area has been shown to contain a system of executive processes that control the nesting of functional segments that combine in hierarchically organized action plans (Koechlin and Jubault, 2006). In the present study, contextual control impairment observed in patients—e.g. disturbance of a particular level of the control hierarchy—could therefore reveal a more specific problem in the hierarchical organization of action representations that would thus impact on the selection of appropriate task-sets.

Obviously, the selection of inadequate action representations may cause some difficulty in planning and organizing adapted behaviours over time. Consistently, we found that impaired contextual control performance was specifically associated with disorganization symptoms as revealed by significant regression scores between the contextual score and both the disorganization score and its formal thought disorders subscore. Although significant, it is noteworthy that this association was of a moderate strength ($R^2 = 0.21$), indicating that only a small proportion of variance in disorganization scores was captured by the deficit we observed. As already suggested by Cohen *et al.* in a previous study (Cohen *et al.*, 1999), this could be due to the fact that the disorganization scale we computed includes several subscales, which may themselves be differentially related to context processing deficits.

Taken together, these results are consistent with a number of previous studies using behavioural settings or neuroimaging techniques. The severity of the disorganization syndrome has been many times associated with the extent of executive deficits (Mahurin *et al.*, 1998; Kravariti *et al.*, 2005). In particular, the profile of performances we observed in the schizophrenia sample is particularly consistent with Cohen *et al.*'s previous reports of a close relationship between disturbances in the processing of context and symptoms of formal thought disorder (Cohen *et al.*, 1999; see also Kerns and Berenbaum, 2003). Our data also fit with several fMRI studies showing that disorganized patients tended to have lower activation in prefrontal regions (BA 9/46, Perlstein *et al.*, 2001; Snitz *et al.*, 2005), the regions that, as predicted by the cascading model, precisely mediate the control of contextual information (Fig. 1).

In the present study, this association further suggests that disorganized behaviour can be partially explained by patients' inability to specifically use contextual information for concomitantly selecting appropriate behavioural representations among competitive ones. This interpretation is strengthened by the fact that this impairment worsened as the influence that contextual cues potentially play in that selection, increased. Finally, given the critical role of Broca's area in the hierarchical organization of human language (Dominey *et al.*, 2003; Musso *et al.*, 2003), impairment at this level of the control hierarchy may also account for clinical manifestations such as disorganized speech. In the light of the cascading model (Koechlin *et al.*, 2003; Koechlin and Jubault, 2006), unexpected topic switches, derailment or tangential responses might indeed arise from an inability to continuously monitor the hierarchical organization of human language, e.g. to coordinate linguistic segments that compose speech in relation to the superordinate goals and subgoals of discourse. As the functional integrity of Broca's area in schizophrenia is still a matter of debate, with previous neuroimaging studies reporting either relatively normal (Perstein *et al.*, 2001; MacDonald *et al.*, 2005) or reduced Broca's activation (Stevens *et al.*, 1998; Snitz *et al.*, 2005), this hypothesis should be taken cautiously, however. In future work, the use of neuroimaging techniques should allow us to test this assumption more directly.

Conclusion

Patients with schizophrenia do not suffer from general cognitive control impairment but rather from a deficit of some control processes. While episodic and sensory controls were found to be spared, contextual control was specifically impaired. In the present study, this is reflected in an impairment in the selection of an appropriate task-set, given a specific perceptual context. Contextual control can be considered as a set of executive processes involved in the hierarchical organization of behaviour (Koechlin and Jubault, 2006). Patients' deficit in cognitive control thus reflects a specific problem in the hierarchical control of action, leading to the selection of inappropriate behavioural representations for current action plans. Moreover, this impairment was a good predictor of disorganization syndrome score, further suggesting that these clinical manifestations might result, at least partially, from a deficit in the combination or selection of hierarchically organized action representations in the motor and, possibly, the verbal domains. Obviously, such a deficit is likely to impact on patients' social functioning. Indeed, adapted social behaviour and interactions crucially depend on the ability to organize actions in the context of both our own internal, but also external goals inferred from other people's behaviour. We therefore believe that bringing to light the mechanisms underlying such ability may provide, in future, valuable tools to account more efficiently for difficulties in social adaptation that patients with schizophrenia encounter in their everyday life.

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