European Psychiatry 28 (2013) 87–93

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Original article

Forgetting what you have checked: A link between working memory impairment and checking behaviors in obsessive-compulsive disorder

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ARTICLE INFO

Article history:
Received 15 April 2011
Received in revised form 30 June 2011
Accepted 3 July 2011
Available online 15 September 2011

Keywords:
Working memory span
Eye movement recordings
Image comparison task
Obsessive compulsive disorder
Checking behavior

ABSTRACT

Background: Compulsive checking behaviors are common in obsessive-compulsive disorder (OCD). Several authors have suggested that these checking rituals could be related to memory deficits. Our aim was to test whether patients with OCD show working memory impairment in relation to their checking behavior.
Methods: We evaluated the verbal and visuospatial components of patients' and controls' working memory using the reading span and backward location span tests. Checking behaviors were measured by recording participants' eye movements during an image comparison task using a non-invasive, infra-red TOBII 1750 eyetracker. Participants were seated, head-free, in a natural position in front of the eyetracker screen where the images were displayed.
Results: Patients with OCD made more gaze moves to compare images than controls. Both patients' working memory spans were reduced, and the patients' deficit in the comparison task was negatively related to their working memory spans.
Conclusions: This work demonstrates that checking behavior in OCD is linked to a general reduction of the patients' verbal and visuospatial working memory span.

1. Introduction

Obsessive-compulsive disorder (OCD) is one of the most prevalent and disabling psychiatric disorders, with a lifetime prevalence of 2.5–4% [21,25]. OCD is characterized by persistent, intrusive obsessions, which cause marked anxiety and distress, and compulsions that serve to neutralize the anxiety generated by the obsessions [24]. The compulsions are behavioral and/or cognitive responses, such as checking behaviors, that generate a rewarding, but only transient, anxiety-free state. Hence, the continuous recurrence of obsessions leads to the endless repetition of compulsive behaviors [20,21,23].

Several authors have suggested that compulsions, and in particular checking behaviors, are caused by an impaired memory for actions, a reduced confidence in one's memory, and/or deficits in "reality monitoring", i.e. in the capacity to determine whether an action was really carried out or merely imagined [7,26]. However, the search for memory deficits in patients with OCD has led to somewhat contradictory data. On the one hand, neuropsychological assessments of patients with OCD have consistently shown impairment of their non-verbal memory. Indeed, a large number of studies demonstrated that both their long term [7,14,15] and immediate (or "working") visuospatial memory [1,27,28] were reduced. On the other hand, many studies suggested that both the working and declarative verbal memory of patients with OCD were normal [7,14,15], although some authors reported that their declarative verbal memory was impaired on tests requiring semantic clustering of the stimuli [14,26]. In the studies in which

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doi:10.1016/j.eurpsy.2011.07.001

no deficit was found, however, verbal working memory was mostly assessed through the very simple WAIS-R backward digit span test [14], and not through more complex tests that measure both the storage and manipulation capacity of working memory [4]. One potential explanation for this rather complex picture is therefore that overall, patients with OCD would be unable to efficiently organize pieces of information, whatever their nature, in order to make them easier to memorize [7]. Hence, some of the memory deficits of OCD patients and, in particular, their working memory deficits may result from executive dysfunction and impaired memory control. If this is true, their verbal working memory deficits can only be revealed by tests that require more complex encoding and retrieval strategies than the simple digits or letters span tests.

Rotgé et al. [22] recently designed an image comparison task to assess the intensity of checking behavior in patients with OCD. Patients with OCD and controls performed a delayed matching-to-sample task in which they could verify their choice as much as they wanted. Participants were presented with an image for a few seconds. Then, a second image appeared and participants had to compare it with the initial image and tell whether the two images were different or identical. Before validating their answer, participants could see the initial image again by pressing a key. The choice screen was then presented again, so that checking could be performed an unlimited number of times. As expected, patients with OCD performed more checking behaviors than control participants, suggesting that this task can be used to quantify patients' checking behaviors and assess their cognitive determinants. However, because participants had to "ask" to check their choice, the patients with good insight might have refrained from using this possibility.

The goal of this study was to test the hypothesis that patients with OCD do show a general working memory impairment that is related to their compulsive checking behavior. The verbal and visuospatial components of patients' working memory were evaluated using tests known to involve both the storage and manipulation of information, namely the reading span test [4] and the backward location span test [8]. The checking behavior was assessed by a modified version of the Rotgé et al.'s [22] task where the two images to be compared were presented on the same screen rather than on two successive slides. A non-invasive eyetracker was used to record the participants' eye movements, and assess their checking behavior by counting the number of times their gaze went from one image to the other. In this situation, participants did not have anymore to explicitly ask for the possibility to check their choice, so that even the patients with good insight were most likely unable to control their checking behavior. Three clinical variables, namely the duration of the pathology since onset, Y-BOCS score and insight score, were used as potential confounding factors in exploring the link between working memory spans and checking behaviour in OCD. Indeed, a recent paper [13] suggested that the poorer the insight of patients with OCD, the greater the intensity of their checking behaviour.

2. Material and methods

2.1. Participants

Participants were 32 consecutive patients with a primary diagnosis of OCD and 32 control volunteers with no history of or current psychiatric illness. None of them had participated in Rotgé et al.'s [22] study. The control volunteers were individually matched with patients for sex, age (to within five years) and years of education. The main participants' characteristics and patients' clinical variables are shown in Table 1. The patients were seen at the specialized university hospital of a midsize French town (centre hospitalier Henri-Laborit, CHL, Poitiers), while the controls were recruited from local community by word of mouth. All participants gave their written, informed consent to participate in the experiment, and the protocol was approved by the local ethics committee.

Patients were examined using the Mini International Neuropsychiatric Interview (version 5.0.0.). Provided that OCD was their dominant disorder, the patients with comorbid psychiatric diagnoses were not excluded from the study (Table 1), except those with current mood episodes. Patients' trait anxiety was assessed as part of routine clinical examination through a French version of the Hamilton Anxiety Rating Scale (HARS), which measures anxiety level on a 0 to 56 (maximum severity) scale (Table 1). Twenty-three of the 32 patients were receiving antidepressants with serotonin reuptake-inhibiting properties alone, or combined with neuroleptics ($n = 3$), anxiolytics ($n = 1$) or both ($n = 1$).

The patients' OCD symptoms (Table 1) were assessed through a French version of the Yale-Brown Obsessive-Compulsive Scale (Y-BOCS) [10,11,19], which measures the severity of OCD symptoms on a 0 to 40 (maximum severity) scale. The Y-BOCS symptom checklist was used to separate the 28 patients who displayed checking compulsions (16 women and 12 men, 87.5%) from the four patients that did not (three women and one man). The patients' insight on their pathology was evaluated using a French version of the Brown Assessment of Beliefs Scale (BABS) [6]. BABS is a semi-structured scale designed to assess insight through seven items covering different insight's dimensions. The BABS total score

Table 1
Main participants' characteristics and patients with OCD's clinical variables, mean values ± standard deviation (S.D.).

Participants' characteristics and clinical variables	Patients with OCD ($n = 32$)	Healthy controls ($n = 32$)
Gender (F/M)	19/13	19/13
Age	37.6 ± 13.3 (range 19–73)	37.7 ± 13.2 (range 19-68)
Age at onset of pathology	16.8 ± 10.0 (range 7–51)	Not applicable
Duration of the pathology (in years)	20.7 ± 11.6 (range 2–48)	Not applicable
HARS score	11.6 ± 3.1 (range 7–18)	Not available
Y-BOCS score	26.1 ± 4.0 (range 21–36)	Not applicable
Insight score	5.8 ± 1.8 (range 4–11)	Not applicable
Pharmacological treatment	23 out of 32 (72%)	None
Cognitive behavioral therapy	None	None
Comorbidity	*Current comorbidity* Social phobia (5 patients) Generalized anxiety disorder (3 patients) Pathological gambling (1 patient) Bipolarity (1 patient) *Past comorbidity* Major depressive episode (23 patients)	No history of axis I psychiatric disorder

ranges from 0 (excellent insight) to 24 (no insight), with the cutoff score for poor insight set at 12.

2.2. General procedure and apparatus

Participants were tested individually. They performed the reading span test, the backward location span task and the image comparison task in that order. The reading span test and image comparison task were performed on the 17″ monitor of a TOBII 1750 eyetracker. The eyetracker was driven via a Fujitsu/Siemens laptop and provided gaze positions at 50 Hz with a precision of 0.5 degree of visual angle. The screen was at a viewing distance of 65.5 ± 7.2 centimeters, so that one degree of visual angle covered about 11.4 millimeters on the screen. Dedicated TOBII software (ClearView 2.7.1) was used to prepare and present the stimuli, to record and analyze eye movement data and to time and characterize all events such as slide appearance and key presses. The backward location span task was performed on a PC-compatible laptop using homemade executable software to control the presentation of stimuli and to record and score responses.

2.3. Evaluation of participants' working memory spans

2.3.1. Reading span test

A French version [5] of the original test [4] was used. The material consists of 100 unrelated test sentences and 10 practice sentences 12–17 words long. All final words of the sentences are nouns matched for mean length and frequency.

Participants read aloud successive sets of two to six sentences. The sentences were presented one by one on the eyetracker screen. Participants could take as much time as needed to read each sentence, but the sentence disappeared when the participant had finished reading it and a new sentence came up on the screen. After the participant had read all sentences in a set, the participant had to give the last word of each sentence in the order in which they were presented. The test started with a practice session of one two-sentence and one three-sentence sets. The experimental session included five successive blocks of five sets of sentences. Each block included one two-sentence, one three-sentence, one four-sentence, one five-sentence and one six-sentence set. In accordance with recent recommendations for scoring the reading span test [9], the span score of each participant was defined as the total number of correctly recalled words for a maximum possible score of 100.

2.3.2. Backward location span task

The backward location span task [8] was a modified, computerized version of the Corsi blocks tapping task [18]. Participants were presented with a five by five grid, in which increasingly long sequences of two to nine randomly located cells turned black one after the other for 1,500 milliseconds. Immediately after each sequence, participants had to reproduce it in the opposite order in an empty grid by clicking on the corresponding cells. The test started with a practice session of three two-cell and three three-cell sequences. The experimental session included 32 sequences of increasing difficulty, four for each set size, namely four two-cell sequences, four three-cell sequences and so on up until four nine-cell sequences. In accordance with recent recommendations for scoring span test performance [9], the participant's visuospatial span score was defined as the total number of correctly recalled cells for a maximum possible score of 176.

2.4. Image comparison task

2.4.1. Material

The image comparison task consisted in telling whether two drawings presented simultaneously on opposite sides of the eyetracker screen were either identical or different. Eight training pairs and 48 experimental pairs of drawings were selected among the material of Rotgé et al. [22]. Each pair included two versions of the same drawing (A and B) that differed in one of the following ways:

- the position and/or orientation of either the whole drawing or of one element were modified (22 cases);
- one element was added or removed (18 cases);
- the color or identity of one element of the drawing was modified (eight cases).

The size and complexity of drawings were also variable. Thirty of them were realistic drawings of humans, animals, objects or scenes, whereas the 18 other ones were composed of abstract lines or shapes. The sizes of the drawings varied from 1.5×2 (width $\times$ height) to 8×8 centimeters.

The A and B versions of each drawing were used to generate four different displays (Fig. 1). Two of them showed identical drawings that were either the A ("AA display") or B ("BB display") version. The two other ones showed the two different versions of the drawing in either the AB ("AB display") or BA ("BA display") order. The minimal space between drawings was nine centimeters, namely about eight degrees of visual angle, so that only one of them could be foveated at any time.

2.4.2. Design and procedure

Following the eye movement calibration procedure, each participant performed the eight training trials followed by 48 experimental trials presented in random order. Each experimental trial was based on one of the 48 pairs of drawings, and thus each drawing was seen once by each participant. In half of the trials, participants were shown either the AA or BB display (12 trials each) and compared identical versions of the drawings. In the other half of the trials, they were shown either the AB or BA display (12 trials each) and compared different versions of the drawing. The assignment of the 48 drawings between the four types of display was counterbalanced so that the type of display was crossed with four sets of drawings (12 per set) and eight groups of four participants.

Each trial began with a "next trial" slide. On pressing the space bar, a central fixation cross appeared for two seconds. Then, the two drawings appeared. Participants had to compare them as quickly as

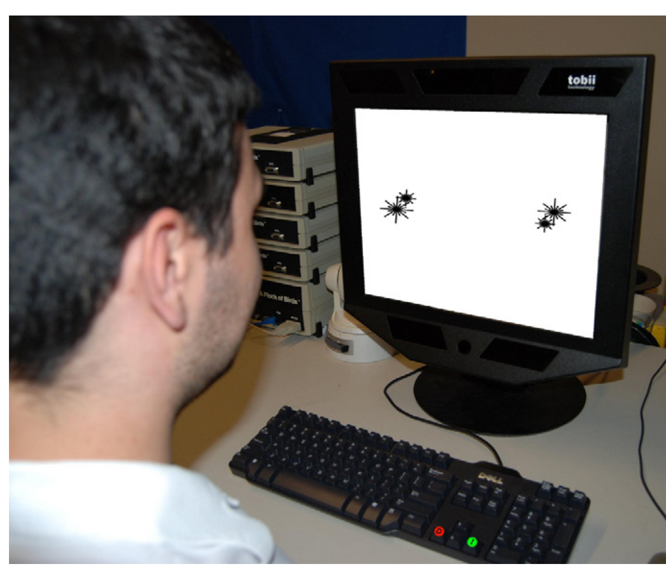

Fig. 1. Photograph of the experimental apparatus with an example of comparison between the different versions of a drawing shown on the eyetracker screen.

possible, but without making mistakes, and to press either one of two keys to indicate whether they were different or identical. During the training trials, a feedback on whether or not the drawings were actually different was given after the participant's answer. No feedback was given during the experimental trials.

2.5. Data analysis

The patients' reading and location span scores were compared with those of controls using unpaired, one-tailed *t*-tests, and effect sizes computed as Cohen's *d*. Multiple regression analyses were conducted to determine whether the patients' working memory span scores could be predicted by clinical variables, namely the duration of the pathology since onset, Y-BOCS score and insight score.

2.5.1. Data from the image comparison task

The error rates, response times, and numbers of gaze moves made between drawings (see below) were used as dependent variables. Because of the heterogeneity of drawings, statistical analyses were performed using items, and not participants, as a random factor. In other words, what was compared were the average response times and numbers of gaze moves between drawings obtained for all patients with OCD on one hand, and all control participants on the other hand, for each one of the 48 pairs of drawings. The error rates were analyzed using non-parametric statistical tests and all mistaken trials were excluded from further analysis.

Response times were measured between the drawings appearance and the participant's key press. Logarithmic transformation was applied to ensure variance homogeneity and normality. Statistical analysis was performed using a two-way ANOVA with the participants' pathological status (patients or controls) and the different or identical nature of the drawings as within-item factors. Effect sizes were computed as partial eta squares (eta_p^2). Multiple regression analyses were then conducted to determine whether the patients' average response times (considering all pairs of drawings) could be predicted by clinical variables.

Eye fixations were defined as any period where gaze stayed for 60 ms or more within a 30 pixels (0.9 degree of visual angle) diameter area. On each display, an "area of interest" (AOI) was defined around each drawing. The AOI limits were set at a 1.5 to 2 cm distance of the drawing's borders depending on its size, and all eye fixations that fell within this rectangle were assigned to that drawing. The distance between the inside borders of the left and right AOIs was at least six centimeters (5.3 degrees of visual angle).

The main eye movement dependent variable was the number of times the participant's gaze moved between drawings before the participant answered, taken as an index of participants' checking behavior. Gaze moves between drawings were defined as any saccade linking a fixation assigned to one drawing with a fixation on the other one. To get rid of interference due to eye-hand coordination processes, fixations made while or after the response key was pressed were excluded from analysis. Following logarithmic transformation, statistical analysis was done as for the response times above.

2.5.2. Relationships between the participants' working memory span scores and their performance on the image comparison task

Regression models were built to check whether, as hypothesized, the patients and controls' working memory span scores could predict their response times and/or the numbers of times their gaze moved between drawings. To assess more precisely whether the patients' impairment revealed by the comparison task also depended on their working memory spans, complementary regression analyses were run using the difference between the average response times (respectively the average numbers of gaze moves between drawings) obtained for each patient and his or her individually-matched control as indices of each patient's deficit.

3. Results

As already shown by others [16], preliminary Mann-Whitney *U*-tests demonstrated that neither the patients' working memory span scores nor their performance on the comparison task depended on their medication status. All patients were therefore pooled together for analyses.

3.1. Working memory spans

As expected, the patients' reading span score (46.3 ± 11.1) was lower ($t[62] = 3.74$, $p < 0.001$, $d = 0.95$) than that of control participants (57.3 ± 12.4). Similarly, the patients' location span score (110.7 ± 20.7) was lower ($t[62] = 3.69$, $p < 0.001$, $d = 0.94$) than that of controls (129.5 ± 20.0). The reading span and location span scores were positively correlated in controls ($R = 0.45$, $p < 0.05$) as well as patients ($R = 0.55$, $p < 0.01$). Among patients, there was no significant correlation between the HARS scores and either one of the working memory span scores. Finally, multiple regression analyses demonstrated that neither the duration of the pathology nor the insight or Y-BOCS scores could significantly predict the patients' reading ($F[1,28] < 2.60$, $p > 0.11$ in both cases) or location span scores ($F[1,28] < 2.41$, $p > 0.13$).

3.2. Image comparison task

3.2.1. Error rates

Within-drawings Wilcoxon signed-rank tests demonstrated that both patients with OCD and control participants made more errors when the drawings to compare were different than when they were identical (respective Z [$N = 48$, d$f = 1$] = 5.65 and 4.58, $p < 0.001$ in both cases). Indeed, patients made in average 4.3 ± 3.6 errors when comparing different drawings (26% error rate over the 16 patients who compared different versions of each drawing) versus 0.3 ± 0.6 errors when comparing identical drawings (1.9% rate). Control participants made 3.2 ± 3.5 errors when comparing different drawings (20.0%) versus 0.6 ± 0.7 errors when comparing identical drawings (3.7%). Besides, patients with OCD made more errors than controls when the drawings to compare were different (Z [$N = 48$, d$f = 1$] = 3.18, $p < 0.01$).

3.2.2. Response times

The two-way ANOVA revealed a main effect of the participants' pathological status ($F[1,46] = 65.36$, $p < 0.001$, $\text{eta}_p^2 = 0.587$). As shown on Table 2, patients with OCD took more time to compare the drawings than controls. There was also a main effect of whether participants had to compare different or identical drawings ($F[1,46] = 110.58$, $p < 0.001$, $\text{eta}_p^2 = 0.706$): They were quicker to tell that the drawings were different than to tell they were identical (Table 2). There was a significant interaction between these two factors ($F[1,46] = 8.01$, $p < 0.01$, $\text{eta}_p^2 = 0.148$). Post-hoc Tukey tests demonstrated that patients with OCD took more time than controls to compare both different ($p < 0.001$) and identical ($p < 0.05$) drawings, but the difference between patients and controls was larger for comparisons between different drawings. Among patients, there was no significant correlation between the HARS scores and the time taken to compare either different or identical drawings. Finally, multiple regression analyses demonstrated that neither the duration of the pathology nor the insight or Y-BOCS scores could significantly predict the time patients took to compare either different ($F[1,28] < 0.45$, $p > 0.51$ in all cases) or identical drawings ($F[1,28] < 0.68$, $p > 0.41$).

Table 2
Response times (in milliseconds) and numbers of gaze moves between the two drawings obtained for patients with OCD and healthy controls in the image comparison task (mean values ± S.D.).

Type of comparison	Dependent variable	Patients with OCD	Healthy controls
Different drawings	Response times	3,007 ± 847***	2,503 ± 939
	Gaze moves between drawings	3.45 ± 1.21***	2.97 ± 1.22
Identical drawings	Response times	4,309 ± 1,349*	3,899 ± 979
	Gaze moves between drawings	5.12 ± 1.16	4.88 ± 1.15

The asterisks (*) indicate where significant differences were found between patients with OCD and their healthy controls (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

3.2.3. Numbers of gaze moves between the two drawings

There was a strong, significant correlation between the average number of gaze moves made between drawings and the response times obtained for each participant. This was true both for patients with OCD and for controls whether the drawings were different ($R = 0.86$ for patients, $R = 0.64$ for controls, $p < 0.001$ in both cases) or identical ($R = 0.82$ for patients, $R = 0.87$ for controls, $p < 0.001$). As for response times, the within-item two-way ANOVA revealed a main effect of the participants' pathological status ($F[1,46] = 20.90$, $p < 0.001$, $eta_p^2 = 0.312$). As shown on Table 2, comparison between the drawings required more gaze moves for patients than for controls. The comparison also required more gaze moves when the drawings were identical (Table 2) rather than different ($F[1,46] = 95.17$, $p < 0.001$, $eta_p^2 = 0.674$). There was again a significant interaction between this factor and the participants' pathological status ($F[1,46] = 6.37$, $p < 0.05$, $eta_p^2 = 0.122$). Post-hoc Tukey tests demonstrated that patients made significantly more gaze moves than controls to compare different ($p < 0.001$) but not identical ($p = 0.27$) drawings. As for response times, there was no significant correlation between the patients' HARS scores and the number of gaze moves they made between either different or identical drawings.

3.3. The participants' working memory span scores predict performance on the image comparison task

Regression models were built to check whether the reading span and backward location span scores could predict patients with OCD and/or controls' response times and numbers of gaze moves between drawings. Because of the rather strong correlation between the two span scores, particularly in patients, separate regressions were performed on each score.

When the drawings were different, the best fit models of response times ($R^2 = 0.367$, $F[3,60] = 11.60$, $p < 0.001$ for the reading span and $R^2 = 0.370$, $F[3,60] = 11.77$, $p < 0.001$ for the location span score) and numbers of gaze moves between drawings ($R^2 = 0.212$, $F[3,60] = 5.39$, $p < 0.01$ for the reading span and $R^2 = 0.246$, $F[3,60] = 6.51$, $p < 0.001$ for the location span score) were obtained using the participants' pathological status as a categorical predictor, and the span score as well as the interaction between span score and pathological status as continuous predictors. The four models revealed that when either one of the participants' span scores increased, both their response times (reading span $\beta = -0.49$, $F[1,60] = 18.65$, $p < 0.001$, $eta_p^2 = 0.237$, location span $\beta = -0.50$, $F[1,60] = 19.62$, $p < 0.001$, $eta_p^2 = 0.246$) and the numbers of gaze moves they made between drawings (reading span $\beta = -0.28$, $F[1,60] = 4.98$, $p < 0.05$, $eta_p^2 = 0.077$, location span $\beta = -0.36$, $F[1,60] = 8.33$, $p < 0.01$, $eta_p^2 = 0.122$) decreased. For response times, there was a significant or marginally significant interaction between the impact of either span score and the participants' pathological status (reading span $\beta = -1.21$, $F[1,60] = 6.59$, $p < 0.05$, $eta_p^2 = 0.099$, location span $\beta = -1.14$, $F[1,60] = 3.32$, $p = 0.07$), such that the correlation between span scores and comparisons times was stronger in patients than in controls. The same interaction was observed for the numbers of gaze moves between drawings, but was only marginally significant or just present as a trend (reading span $\beta = -0.95$, $F[1,60] = 3.25$, $p = 0.08$, location span $\beta = -0.92$, $F[1,60] = 1.82$, $p = 0.18$).

In contrast, when the drawings were identical, there was no significant relationship between the participants' working memory span scores and either their response times or the numbers of gaze moves they made between drawings. None of the best fit models did significantly predict the participants' performance ($F[3,60] < 1.51$, $p > 0.22$ in all cases).

3.3.1. Link between the patients' impairment on the comparison task and working memory span scores

The differences between the response times and numbers of gaze moves between drawings of each patient and her or his individually-matched typical control was used to build further regression models with patients' and controls' reading span (or location span) scores as the two predictors. When participants compared different drawings, the reading span scores predicted the response time increase for each patient relative to her or his matched control ($R^2 = 0.245$, $F[2,29] = 4.70$, $p < 0.05$). The difference between patients and controls was negatively related to the patients' ($\beta = -0.49$, $F[1,29] = 8.74$, $p < 0.01$, $eta_p^2 = 0.232$) but not the controls' ($\beta = -0.03$, $F[1,29] = 0.03$, $p = 0.87$) reading span scores (Fig. 2A). Similarly, the location span scores predicted the response time increase observed in each patient ($R^2 = 0.261$, $F[2,29] = 5.12$, $p < 0.05$). Again, the difference with controls was negatively related to the patients' ($\beta = -0.51$, $F[1,29] = 10.10$, $p < 0.01$, $eta_p^2 = 0.258$) but not the controls' ($\beta = 0.10$, $F[1,29] = 0.41$, $p = 0.53$) location span scores (Fig. 2B). Finally, the location span scores (but not the reading span scores, for which the regression model was not significant) also predicted the increase of the number of gaze moves between drawings observed in patients relative to their matched controls ($R^2 = 0.220$, $F[2,29] = 4.09$, $p < 0.05$), and again the difference with controls was negatively related to the patients' ($\beta = -0.47$, $F[1,29] = 8.18$, $p < 0.01$, $eta_p^2 = 0.220$) but not the controls' ($\beta = 0.05$, $F[1,29] = 0.10$, $p = 0.75$) scores. In other words, the lower the patients' working memory span scores, the greater their impairment on the comparison task.

No significant prediction of the patients' increase of response time or of the number of gaze moves between drawings was possible when the participants compared identical drawings. None of the regression models was significant for either the reading or location span score ($F[2,29] < 0.41$, $p > 0.66$ in all cases).

4. Discussion

4.1. Working memory spans of patients with OCD

In accordance with our hypothesis, patients with OCD displayed lower reading and location span scores than control participants, indicating that both the verbal and visuo-spatial components of working memory are impaired in OCD. This result confirms that previous reports of a spared verbal working memory in OCD [7,14,26] were probably due to the use of too simple verbal tests, which did not measure both the storage and manipulation capacity of the working memory. This also supports the idea that the

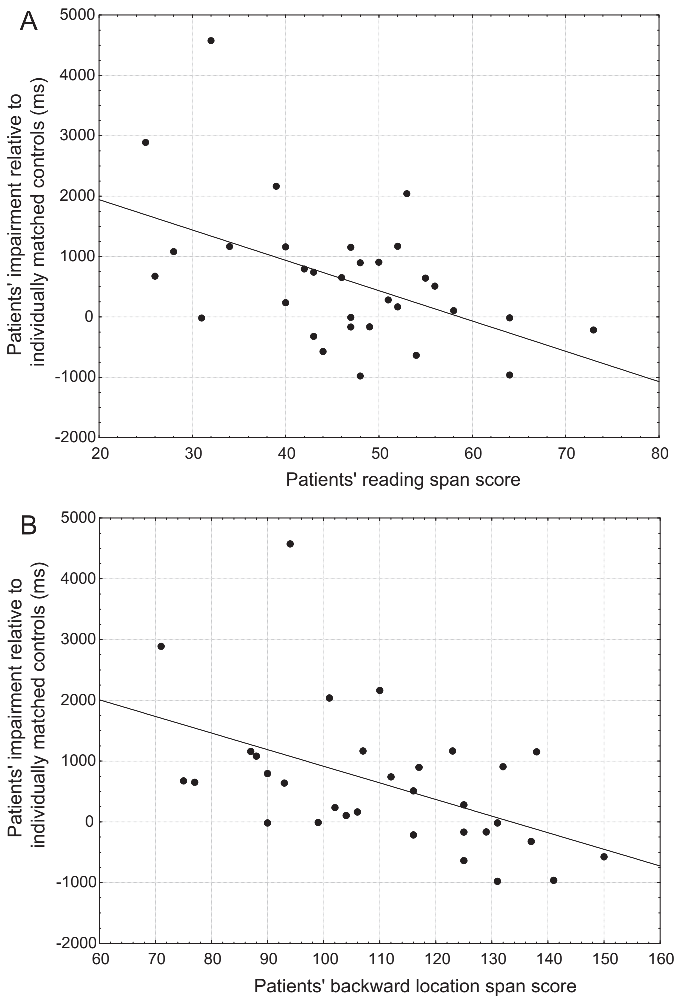

Fig. 2. A. Correlation between the patients' impairment on the comparison of different drawings relative to individually matched controls and the patients' reading span score. B. Correlation between the patients' impairment on the comparison of different drawings relative to individually matched controls and the patients' backward location span score.

patients' working memory deficit may result from abnormalities in memory control and/or executive functioning, which have been proposed as potential endophenotypes for OCD [2,3,12,17].

4.2. Performance of patients with OCD on the comparison task

As expected from Rotgé et al.'s [22] study, patients took more time to compare drawings than controls. They made more gaze moves between the two versions of the drawings, suggesting that they checked their answers more than control participants. Hence, the patients' longer response times did not result from some general slowing of motor and/or decision processes that could have been induced by medication. Patients also made more errors than controls.

The patients' performance was worse when comparing different rather than identical drawings. In particular, the patients' checking behavior was more intense than that of controls only when the drawings were different, and especially when the difference was easy to spot. This contrasts with Rotgé et al.'s [22] data, who reported that patients with OCD experienced a greater exacerbation of their checking behavior when the images were identical. This difference might result from the distinct modes of presentation of the two images (sequential versus simultaneous) and the different checking behavior assessment (number of voluntary checks versus number of gaze moves between drawings) used in the two studies. In Rotgé et al.'s [22] study, participants had to "ask" to check their choice, and the patients with good insight might have consciously refrained from using this possibility. Here, the patients only had to move their eyes to verify their answer, which should minimize insight involvement. Another explanation might be that in Rotgé et al.'s [22] study, participants were instructed to tell whether the two images were identical using a right/wrong answer, whereas in the present work they were asked to press either one of two keys to indicate whether the drawings were different or identical.

4.3. A link between the working memory capacity and checking behavior of patients with OCD

In accordance with our main hypothesis, there was a strong relationship between the participants' working memory capacity and performance, such that low working memory spans were associated with both longer times to compare different versions of the drawings and more gaze moves between the two drawings, i.e. a more intense checking behavior. Regression analyses demonstrated that both the reading and location span scores could predict participants' response times and number of gaze moves between drawings, and that the correlation was stronger among patients than among controls. In addition, and most importantly, both the patients' reading and location span scores predicted the response time increase observed in each patient relative to her or his matched control, while the location span score predicted the relative increase in the number of gaze moves made between drawings. The patients who were the most impaired on the image comparison task were those that had the lowest verbal and visuospatial working memory capacities. Altogether, this strongly suggests that the intensity of patients' behavioral symptoms, and in particular of their checking behavior, was intimately linked to their working memory impairment.

The strong link between the patients' working memory deficits and performance supports the idea that checking behaviors are associated with an impaired capacity to keep in mind the detailed characteristics of each drawing, or a reduced confidence in one's short-term memory [7,26]. The patients' working memory deficit would affect both the verbal and visuospatial components in the same way and appears to be rather general. Since this deficit is only revealed by tests that involve storage and manipulation of information within working memory, one appealing hypothesis is that part of the patients' working memory would actually be kept busy by their obsessions and ruminations. This would permanently reduce the patients' working memory storage and processing capacity available for other tasks independently of the verbal or visuospatial character of the information to be retained and manipulated.

A limitation of the present work is that several alternative interpretations of the data are possible. The lack of significant correlation between the patients' HARS scores and their working memory spans, their response times or the number of gaze moves they made between drawings suggests that their working memory deficit and the higher intensity of their checking behavior were not due to a higher general anxiety level (trait anxiety). However, we cannot exclude that the patients' anxiety state at the time of testing, which was not assessed in the present study, might have reduced their working memory spans and modified their performance on the image comparison task. As briefly stated above, low confidence in one's ability and memory is another variable that was not measured and that may have contributed to the patients' lower performance on tests. Further experiments are needed to address these alternative explanations of the findings. For instance, future experiments could compare the patients' and controls' data with those of anxious psychiatric patients suffering from general anxiety disorder, social phobia or agoraphobia, or with data obtained in unaffected relatives of patients with OCD.

In contrast with what was expected, there was no significant relationship between the patients' clinical variables (duration of the pathology and insight or Y-BOCS scores) and either the working memory span scores or image comparison performance. This suggests that none of them were actually linked with the intensity of the pathology, and may imply that neither the working memory measures nor the image comparison task may be used to evaluate the severity of OCD. This result contrasts with that of Jaafari et al. [13], who found that patients with poor insight performed more checking behaviors during the original Rotgé et al.'s [22] image comparison task. The discrepancy may result from the fact that whereas in the original Rotgé et al.'s [22] task, people had to actively press a key to see the initial image again, participants in the present study just had to move their eyes between the two images. Another possible explanation, however, is that the variability of the Y-BOCS and insight scores of the patients tested in that work was actually low. All patients had a rather severe condition (Y-BOCS score > 20) but had a good insight on their pathology (insight score < 12). The patients' population might thus have been too homogeneous for significant associations between the patients' behavior and clinical variables to be revealed.

5. Conclusion and perspectives

This work demonstrates for the first time that the compulsions and checking behavior of patients with OCD are linked to a general reduction of their working memory span. It confirms that the image comparison task introduced by Rotgé et al. [22] is an interesting research tool to characterize the checking behavior and cognitive deficits of patients with OCD.

6. Contributions of each author to the paper

Nematollah Jaafari contributed to the conception and design of the experiments and the interpretation of data. He drafted the article with N. Vibert and approved the final version to be submitted.

Mickaël Frasca contributed to the design of the experiments. He obtained most of the data, contributed to their analysis and approved the final version to be submitted.

François Rigalleau contributed to the conception and design of the experiments and to the interpretation of the data. He revised the article critically for important intellectual content and approved the final version to be submitted.

Fady Rachid, Roger Gil, Jean-Pierre Olié, Dominique Guehl, Pierre Burbaud, and Bruno Aouizerate revised the article critically for important intellectual content and approved the final version to be submitted.

Jean-Yves Rotgé contributed to the conception and design of the experiments, revised the article critically for important intellectual content and approved the final version to be submitted.

Nicolas Vibert contributed to the conception and design of the experiments as well as the analysis and interpretation of data. He drafted the article with N. Jaafari and approved the final version to be submitted.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgements

This study was promoted by the ''Unité de Recherche Clinique Intersectorielle en Psychiatrie'' of the Centre Hospitalier Henri-Laborit, which received financial support from the Agence Régionale de la Santé de Poitou-Charentes. N. Jaafari was supported by a financial support, « bourse chercheur invité », of the Région Poitou-Charentes

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