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Dopamine, Paranormal Belief, and the Detection of Meaningful Stimuli

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Abstract

■ Dopamine (DA) is suggested to improve perceptual and cognitive decisions by increasing the signal-to-noise ratio. Somewhat paradoxically, a hyperdopaminergia (arguably more accentuated in the right hemisphere) has also been implied in the genesis of unusual experiences such as hallucinations and paranormal thought. To test these opposing assumptions, we used two lateralized decision tasks, one with lexical (tapping left-hemisphere functions), the other with facial stimuli (tapping right-hemisphere functions). Participants were 40 healthy right-handed men, of whom 20 reported unusual, "paranormal" experiences and beliefs ("believers"), whereas the remaining participants were unexperienced and critical ("skeptics"). In a between-subject design, levodopa (200 mg) or placebo administration was balanced between belief groups (double-blind procedure). For each task and visual field, we calculated sensitivity (d') and response tendency (criterion) derived from signal detection theory. Results showed the typical right visual field advantage for the lexical decision task and a higher d' for verbal than facial stimuli. For the skeptics, d' was lower in the levodopa than in the placebo group. Criterion analyses revealed that believers favored false alarms over misses, whereas skeptics displayed the opposite preference. Unexpectedly, under levodopa, these decision preferences were lower in both groups. We thus infer that levodopa (1) decreases sensitivity in perceptual–cognitive decisions, but only in skeptics, and (2) makes skeptics less and believers slightly more conservative. These results stand at odd to the common view that DA generally improves signal-to-noise ratios. Paranormal ideation seems an important personality dimension and should be assessed in investigations on the detection of signals in noise. ■

INTRODUCTION

Dopamine (DA) is a neurotransmitter in the extrapyramidal motor system and a neuromodulator involved in motivation, emotion, and cognition (e.g., Gibbs, Naudts, Spencer, & David, 2007; Smith, Li, Becker, & Kapur, 2006; Nieoullon, 2002; Middleton & Strick, 2000; Previc, 1999). It is assumed to improve perceptual and cognitive decisions by increasing the signal-to-noise ratio (SNR), that is, to modulate neuronal activity by enhancing the ability of neurons to transmit signals and reduce distortion by noise (Seamans & Yang, 2004; Spitzer & Walter, 2003; Spitzer, 1997; Cohen & Servan-Schreiber, 1993).

Links between DA and schizophrenia were originally suggested by the observation that DA antagonistic treatment can ameliorate positive symptoms in patients with schizophrenia (Laruelle & Abi-Dargham, 1999; Davidson et al., 1987; Carlsson & Lindqvist, 1963), whereas DA agonistic treatment results in a deterioration of such symptoms (Sekine et al., 2001; Janowsky & Risch, 1979). In healthy populations, DA agonists not only boost learning (Breitenstein et al., 2006; Knecht et al., 2004) but have also the potential to trigger psychotic symptoms (Sekine et al., 2001; Abi-Dargham et al., 1998; Angrist & Gershon, 1970). Furthermore, DA overmedication can produce psychosis in patients with Parkinson's disease (Factor & Molho, 2004; Kuzuhara, 2001). In a nutshell, acute psychosis is generally considered a consequence of a hyperdopaminergic state (Howes & Kapur, 2009; Kapur, 2003; Laruelle & Abi-Dargham, 1999; Davis, Kahn, Ko, & Davidson, 1991; Carlsson & Lindqvist, 1963). In this context, a number of behavioral DA-responsive studies with unmedicated patients have specifically implicated the right (RH) rather than the left hemisphere (LH) (Mohr, Landis, Bracha, Fathi, & Brugger, 2003; Malaspina et al., 2000; Bracha, Livingston, Clothier, Linington, & Karson, 1993).

Against these clinical findings, the notion that DA would increase the SNR in neural networks appears paradoxical. Psychotic symptoms are associated with a poor discrimination between relevant and irrelevant stimuli, suggesting *impaired* rather than improved perceptual sensitivity. For example, positive psychotic symptoms in patients with schizophrenia are often associated with different kinds of source monitoring impairments (Anselmetti et al., 2007) such as reality-monitoring deficits in terms of a

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confusion between perception and imagination (Brebion, Smith, Gorman, & Amador, 1997; Frith, 1992), disrupted self–other differentiation (Lee, Kwon, Shin, Lee, & Park, 2007; Kircher & Leube, 2003; Hemsley, 1998), and the failure to distinguish between internal and external stimulation (Brebion, David, Bressan, Ohlsen, & Pilowsky, 2009; Henquet, Krabbendam, Dautzenberg, Jolles, & Merckelbach, 2005; Ford, Mathalon, Heinks, et al., 2001; Ford, Mathalon, Kalba, et al., 2001). Source monitoring deficits have also been observed in healthy individuals with high level of psychotic-like experiences (Laroi, D'Argembeau, Bredart, & van der Linden, 2007; Allen, Freeman, Johns, & McGuire, 2006). Accordingly, signal detection parameter have unequivocally shown a decreased rather than increased perceptual sensitivity in patients with auditory hallucinations (Ishigaki & Tanno, 1999). Furthermore, a lowered sensitivity in detecting a mismatch between expectancy and experience was described. This reduction, accompanied by blood flow changes in right frontal cortex, correlated with delusion severity in psychotic patients (Corlett et al., 2007).

Paranormal belief in healthy participants (e.g., the belief in extrasensory, psychokinetic and prophetic abilities) has been associated with both creative and disordered thought (Claridge, 2009; Leonhard & Brugger, 1998). For instance, individuals with paranormal belief evidence a marked willingness to perceive "patterns in noise" (Reed et al., 2008; Bell, Reddy, Halligan, Kirov, & Ellis, 2007; Brugger & Graves, 1997b) and are more inclined than those skeptical about such abilities to attribute meaning to random associations (Mohr, Landis, & Brugger, 2006; Gianotti, Mohr, Pizzagalli, Lehmann, & Brugger, 2001; Pizzagalli, Lehmann, & Brugger, 2001). Although the creative aspects of paranormal thought have been emphasized by some authors (Folley & Park, 2005; Weinstein & Graves, 2002; Gianotti et al., 2001; Claridge, Pryor, & Watkins, 1990), others have equally stressed its conceptual similarity to psychotic symptoms (Brugger & Graves, 1997b; Kreweras, 1983). Thus, a reduced criterion to acknowledge the presence of a signal not only increases the chances to creatively detect a real stimulus but also bears the risk of Type II errors, that is, hallucinatory perceptions and delusional inferences. These aspects of paranormal belief have been conceptualized by Eckblad and Chapman (1983) as an indicator of the positive phenomenology of schizotypy (i.e., a nonclinical analogue of positive psychotic symptoms).

The link between positive symptoms of psychosis and paranormal/positive schizotypal traits is further evidenced by studies showing that psychometrically assessed positive schizotypal individuals, even if completely healthy, perform similarly to patients with schizophrenia in sensory (Mohr, Rohrenbach, Laska, & Brugger, 2001; Kwapil, Chapman, Chapman, & Miller, 1996), cognitive (Tallent & Gooding, 1999; Duchene, Graves, & Brugger, 1998), and attentional tasks (Mohr, Bracha, & Brugger, 2003; Sarkin, Dionisio, Hillix, & Granholm, 1998; Brugger & Graves, 1997a). Of particular relevance to the present study, these similarities are also evident for lateralized neuropsychological functions (Brugger, 2007; Mohr, Bracha, et al., 2003; Barnett & Corballis, 2002; Pizzagalli et al., 2000; Chapman & Chapman, 1987a). Furthermore, neuropharmacological studies pointed to an enhanced dopaminergic responsivity in both persons with schizotypy (Siever et al., 1993) and schizophrenia (Davidson & Davis, 1988; Pickar et al., 1984).

We here investigated whether DA indeed modulates SNR and/or response bias (Reed et al., 2008; Brugger & Graves, 1997b) in participants with paranormal experiences and beliefs ("believers") as compared to individuals with a critical attitude toward paranormal phenomena ("skeptics"). In order to account for a potential right hemispheric shift of dopaminergic involvement in paranormal belief, we used a double-blind levodopa/placebo design and two lateralized tachistoscopic tasks, one with a known advantage of the LH (lexical decision task [LDT]) and one with a processing advantage of the RH (facial decision task [FDT]). Using classical signal detection analysis (Gescheider, 1997; Green & Swets, 1966), we determined sensitivity (d') and response tendencies (criterion C). Because we argued against the notion of DA increasing SNR, we expected (1) an overall reduced detection sensitivity (lower d') in individuals in the levodopa as compared to the placebo group, especially for the believers. In addition, we predicted (2) a generally looser response criterion (lower criterion C) in individuals in the levodopa as compared to the placebo group, again, especially for the believers. Finally, we hypothesized that (3) this effect would be more prominent for RH compared to LH processing for both sensitivity and criterion measures.

METHODS

Participants

Forty healthy men were recruited by a classified advertisement in a local newspaper and flyers posted in the Zurich University district. The study was introduced as an "experiment assessing the role of DA on cognitive functions." We mentioned that blood samples would be taken, and announced an unspecified reimbursement. Critically, the recruitment text for the believers contained the phrase "You do not only consider extrasensory perception a theoretical possibility but you think you are using your own paranormal abilities in everyday situations" (without further justification of why this was a requirement). A contact telephone number and electronic mail address were included. Initially, via standardized telephone interviews (Campbell, 2000), we excluded persons with a personal or first-degree family history of neurological and psychiatric disease, including serious learning disabilities and drug abuse (casual tetrahydrocannabinol consumption was not considered an abuse if the last consumption was more than 2 months ago). Included

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participants were sent a brief information brochure (by regular mail) about the role of DA in the central nervous system, including potential side effects if it was taken at high doses. It also mentioned the requirement to fill in several questionnaires and stated the approximate duration of the procedure ("1 to 2 hours") and the financial reimbursement (Swiss Francs/CHF 50). After 20 believers were selected, 20 skeptics were recruited and selected (same inclusion criterion as for believers) who responded to the same recruitment procedure, using an identical advertisement to the first except that the passage referring to belief in the paranormal now stated: "You have a skeptical attitude toward so-called paranormal phenomena and do not generally believe in the existence of extrasensory perceptions like telepathy, clairvoyance and precognition." Additionally, these skeptics were individually matched to the believers regarding age and educational background (see Table 1). Right-handedness (self-reported at the time of the telephone interview) was later confirmed quantitatively with the 13-item scale by Chapman and Chapman (1987b). Skeptics and believers did not differ from one another in age [$t(38) = 0.20$, $p = .84$], education [$t(38) = 1.57$, $p = .13$], and the strength of right-handedness [$t(38) = 1.23$, $p = .23$].

All participants provided written informed consent to participate in the experiment that had been approved by the local Ethics committee.

Questionnaires

Australian Sheep–Goat Scale (ASGS)

This 18-item visual analog scale (Thalbourne & Delin, 1993) assesses both *belief* in paranormal phenomena (specifically telepathy, clairvoyance, precognition, and psychokinesis) and self-perceived *abilities*. A sample item is: "I am completely convinced that I have had at least one premonition about the future that came true and which (I believe) was not just a coincidence." Each item is scored from 0 to 13 reflecting the number of centimeters the participant's answer mark was displaced from the end of the line. Total scores on the ASGS may thus range from 0 to 234, with higher scores indicating stronger experiences and self-perceived abilities.

Table 1. Descriptive Data of the Study Sample

	Skeptics (n = 20)		*Believers (n = 20)*	
	Mean (SD)	*Range*	*Mean (SD)*	*Range*
Age (years)	28.4 (4.5)	21–39	28.7 (4.8)	21–38
Education (years)	16.3 (2.6)	12–20	15.1 (2.2)	12–20
ASGS	39.0 (25.4)	1–102	168.9 (30.4)	114–222
MI	4.1 (2.9)	0–12	20.0 (3.79)	13–26
Handedness	13.9 (1.2)		14.5 (2.0)	

Magical Ideation (MI) Scale

We assessed participants' MI with a validated true–false 30-item questionnaire that includes items such as "I sometimes have a feeling of gaining or losing energy when people look at me or touch me," or "Some people can make me aware of them just by thinking about me." Scores range from 0 to 30, with higher scores indicating more pronounced magical thinking. The scale is published in full in Barnett and Corballis (2002) and in Eckblad and Chapman (1983), and normative data can be found in Garety and Wessely (1994).

Lateralized Tachistoscopic Tasks

Lexical Decision Task

Stimuli were pairs of four-letter strings, one string exposed to the left visual field (LVF), the other simultaneously to the right visual field (RVF) (exposure time = 140 msec, horizontal eccentricity = 1.5° to 3.0° of visual angle; Regard, Landis, & Graves, 1985; Graves, 1983). All letters were written in black Helvetica font (18 points) and presented on a computer screen (gray background). The following LVF/RVF letter string combinations were presented in a pseudorandomized sequence: 12 word/nonword pairs, 12 nonword/word pairs, and 24 nonword/nonword pairs. Only one-syllable or two-syllable German function words were used as targets. These have low pictorial and associative properties and are thus most likely to consistently recruit LH network activation (Sabsevitz, Medler, Seidenberg, & Binder, 2005). Sample stimuli are *because* ("weil"), *since* ("seit"), or *hardly* ("kaum") (see Figure 1, left).

Facial Decision Task

Stimuli were pairs of faces and "nonfaces" (Heider & Groner, 1996). The faces were photographs (black on gray background) of men and women, whereas the "nonfaces" had scrambled eyes–nose–mouth configurations. All stimuli appeared without face outlines or hairlines ("oval faces"). One face or scrambled face was exposed to LVF, the other simultaneously to RVF (exposure time = 140 msec, horizontal eccentricity = 2.6° to 4.3° of visual angle). The following LVF/RVF face/nonface combinations were presented in a pseudorandomized sequence: 12 face/nonface pairs, 12 nonface/face pairs, and 24 nonface/nonface pairs (see Figure 1, right).

During both decision tasks (counterbalanced order), individuals were asked to rest their head on a chin rest, and to fixate their gaze on a cross in the center of the screen (see Figure 1). On seeing a meaningful word (or face, respectively) in LVF (RVF), they had to press a key with their left (right) hand. On not seeing a meaningful word (face) on either side, they had to press the space bar with both thumbs (Figure 1). Participants were instructed to respond as quickly and accurately as possible and to maintain central fixation throughout the task. Participants were tested

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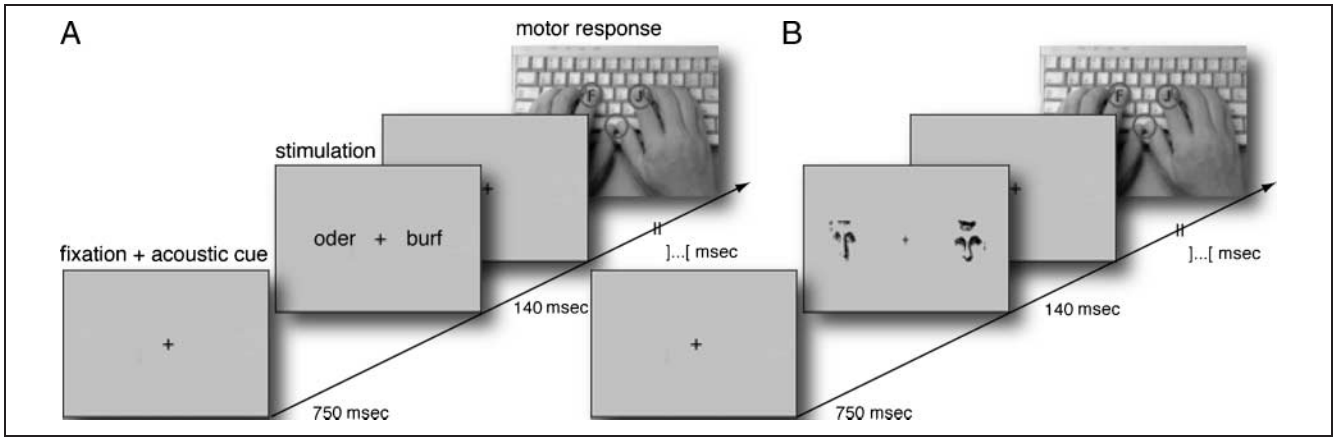

Figure 1. Time course of stimulations in the lexical (A) and facial (B) decision task. After 750 msec (fixation of a central cross), a stimulus was exposed for 140 msec and participants had to press one of two lateral keys depending on the side where a meaningful word (A) or face (B) had been exposed (space bar response for two nonsense words or scrambled faces; 50% of trials). Participants were instructed to respond as quickly and accurately as possible and to fixate their gaze on a cross in the center of the screen.

individually, and light and contrast conditions were kept constant across participants. We assessed accuracy and reaction times (RTs) for correct responses.

Double-blind Procedure

L-Dopa Administration

The study was a randomized, double-blind between-subject levodopa/placebo design. Creation of the randomization code and substance wrapping was performed by a neurologist (H. H.). H. H. was not involved in the behavioral testing, but was available in case of medical emergencies and provided decoding information to the main investigator (P. K.) after all participants had been tested. A dual-release formulation of 200 mg levodopa/50 mg benserazide (Madopar DR; Roche Pharma AG, Reinach, Switzerland) with a fast absorption within the first hour and sustained concentration levels thereafter (Gasser, Jorga, Crevoisier, Hovens, & van Giersbergen, 1999) was administered. Each participant had been strictly instructed to refrain from any food intake between noon and the beginning of the experiment at 3:30 pm. Participants had also been told not to consume alcohol or any other drugs for at least 24 hr before testing. Compliance with these requests were 100% by self-report.

At the end of behavioral testing, participants were asked (questionnaire) which substance they thought they had received, and what they expected the substance effects to be.

L-Dopa Blood Serum Concentrations and Efficacy of Double Blinding

In order to ensure that participants were under significant levodopa concentration throughout the experiment, two blood samples (5–7 ml each) were drawn. The first was collected 30 min after drug administration, just before the two detection tasks. Immediately after behavioral testing, a second sample was drawn. Blood plasma was separated by centrifugation, and the samples were immediately frozen at −80°C for later high-pressure liquid chromatography for electrochemical detection (see Mohr, Landis, Sandor, Fathi, & Brugger, 2004 for further details). No levodopa was detected in the placebo group. In the levodopa group, the mean levodopa serum concentration was 176.95 ± 163.16 ng/ml for the first blood sample and 217.55 ± 106.28 ng/ml for the second blood sample [$t(19) = -0.852, p = .405$].

Data Analysis

To test for a DA influence on SNR as a function of individuals' paranormal belief, we first determined the signal detection theory parameters (1) d' (sensitivity) and (2) the observer's response bias (criterion C) (Gescheider, 1997; Green & Swets, 1966) for each visual field (LVF, RVF) and task (LDT, FDT). Responses were scored as hits for trials on which a real stimulus (a word in the LDT and a face in the FDT) had on the side of the participant's keypress. False positives were responses to nonwords or scrambled faces, respectively. Trials on which a stimulus was presented but the response was made on the wrong side (i.e., confusion errors) were planned to be counted as misses (no such error occurred in the present dataset). d' is a pure index of stimulus detection sensitivity uncontaminated by location of the observer's criterion. Higher d' values indicate better stimulus detection sensitivity. Lower C values reflect a looser response tendency ("*YES* answer bias"), and higher C values indicate a stricter response tendency ("*NO* answer bias"). These two main measures were subjected to two major analyses, (1) and (2), that is, two separate four-way repeated measures ANOVAs with substance group (levodopa vs. placebo) and belief group (believers vs. skeptics) as between-subject factors and task (LDT, FDT) and visual field (LVF, RVF) as repeated within-subject factors.

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In addition, to facilitate comparison of the results with those of previous studies (e.g., Mohr, Krummenacher, et al., 2005; Brugger, Gamma, Muri, Schafer, & Taylor, 1993), we also assessed (3) RTs for correct decisions, and calculated laterality indices as previously used (RT correct LVF − RT correct RVF)/(RT correct RVF + RT correct LVF) (Mohr, Krummenacher, et al., 2005; Marshall, Caplan, & Holmes, 1975). A positive value indicates an RVF/LH advantage and a negative value an LVF/RH advantage. These indices were subjected to a three-way repeated measures ANOVA with substance group (levodopa vs. placebo) and belief group (believers vs. skeptics) as between-subject factors and task (LDT, FDT) as repeated within-subject factor. In case of significant interactions, single post hoc comparisons (Newman–Keuls) were performed correcting for multiple comparisons. Homogeneity of variances in the signal detection measures was controlled using Levene's test.

Nonparametric (Spearman) correlation (r_s) procedures were used throughout in order (1) to be more conservative when running a large number of correlations on small groups ($n = 10$) and because an interval level could not be guaranteed for the questionnaire data.

If not stated otherwise, all p values are two-tailed, and the significance level was set to $\alpha = .05$.

One participant did not obey the LDT instruction (administered before the FDT in his case) and pressed solely the nontarget key in a stereotyped manner. LDT data were thus available from only 39 participants. All other comparisons are based on the originally recruited 40 participants.

RESULTS

Double-blind Procedure

None of the participants reported any remarkable side effects of placebo/levodopa intake. Chi-square analyses of the number of individuals with correct versus incorrect guesses in the postexperimental assessment revealed that neither skeptics (11 correct substance detections consisting of 3 hits and 8 correct rejections and 9 false substance detections consisting of 7 miss and 2 false alarms; $\chi^2 = 0.20$, $p = .66$) nor believers (12 correct substance detections consisting of 5 hits and 7 correct rejections and 8 false substance detections consisting of 5 miss and 3 false alarms; $\chi^2 = 0.80, p = .37$) could reliably guess what kind of treatment they had received.

Questionnaire Data

Two separate two-way ANOVAs with substance group (levodopa vs. placebo) and belief group (believers vs. skeptics) as between-subject factors, once on MI scores and once on ASGS scores, revealed significant main effects for belief group in both cases [MI: $F(1, 36) = 229.85, p = .000$; ASGS: $F(1, 36) = 215.30, p = .000$]. Believers' ASGS and MI scores were significantly larger than the respective values for the skeptics (see Table 1). As indicated by nonsignificant main effects in both ANOVAs, mean MI scores of the levodopa (11.1 ± 8.5) and placebo (13.0 ± 8.9) groups were comparable [$F(1, 36) = 3.32, p = .08$] as were ASGS scores [levodopa: 99.6 ± 75.5; placebo: 108.3 ± 68.7; $F(1, 36) = 0.98, p = .33$]. Interactions were not significant [$F(1, 36) < 1.02, p > .32$].

A split at the median MI scale score (12.5) into a high and low MI group revealed that all participants with ASGS scores above the median (ASGS = 108) belonged to the high MI group, and all participants with ASGS scores below the median to the low MI group. Despite only moderate item-overlap, raw scores on the MI and the ASGS inventories were positively correlated ($r_s = .92, p < .000$).

Lateralized Stimulus Detection: (1) Sensitivity Data

The four-way ANOVA for d' measures revealed a significant main effect for substance group [$F(1, 35) = 6.13, p = .02$]; d' was lower in the levodopa (1.53 ± 0.49) than placebo (2.03 ± 0.72) group. There was also a main effect for task [$F(1, 35) = 6.19, p = .02$] with d' being higher in the LDT (1.97 ± 0.12) than in the FDT (1.54 ± 0.13). Among the two-way interactions, those between visual field and task [$F(1, 35) = 4.96, p = .03$], and belief and substance group [$F(1, 35) = 8.68, p = .006$; see Figure 2A] were significant. As to the first interaction (visual field and task), post hoc comparisons revealed a higher d' for RVF than LVF in the LDT ($p = .01$), and no difference in d' between visual fields in the FDT ($p = .69$). Moreover, for RVF presentations, d' was higher in the LDT than in the FDT ($p = .006$), with no task difference being observed for LVF presentations ($p = .66$). As to the second interaction (belief and substance group), post hoc comparisons showed that d' was comparable between belief groups in the levodopa group ($p = .61$), but there was a higher d' in skeptics as compared to believers in the placebo group ($p = .008$). Moreover, for believers, d' was comparable in the substance groups ($p = .74$), but for skeptics, d' was lower in the levodopa than in the placebo group ($p = .003$; see Figure 2A).

The three-way interaction between paranormal belief, task, and visual field [$F(1, 35) = 3.7, p = .06$] just failed to reach conventional significance level. It indicated that for RVF presentations, the believers' sensitivity was lower for face than word detections ($p = .042$), and skeptics' sensitivity was higher for RVF compared to LVF presentations in the LDT ($p < .01$; see Supplemental Figure at http://neuro-psychologie.net/SF.pdf). No other main effects or interactions were significant (all post hoc tests revealed that this trend indicates F values ≤ 2.85, corresponding p values ≥ .10).

Correlations analyses between belief and sensitivity revealed that skeptics' LVF/RH d' in the LDT was significantly positively correlated to raw scores on the ASGS ($r_s = .78, p < .001$; Figure 3A) in both substance groups (placebo group: $r_s = .72, p = .02$; levodopa group: $r_s =$

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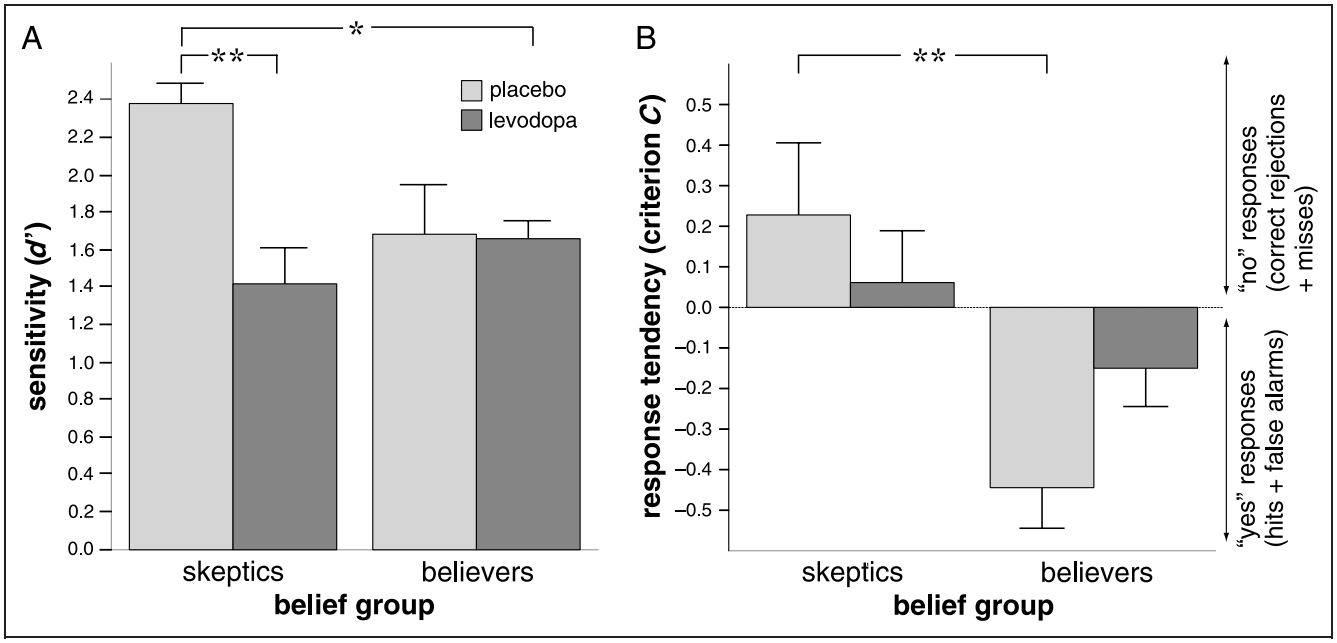

Figure 2. (A) d' values of detection sensitivity (mean ± *SEM*). (B) Values of response criterion *C* (mean ± *SEM*). Data are averaged over tasks and hemispheres, but displayed separately for the two belief and substance groups.

.86, $p = .001$). For neither substance group, a comparable correlation was found for RVF/LH sensitivity ($r_s < -.12$, $p > .73$), nor were believers' ASGS raw scores (calculated separately for both substance groups) correlated with d' measures in the LDT ($r_s < -.10$, $p > .78$ for LVF/RH stimulations; $r_s > .08$, $p > .85$ for RVF/LH stimulations). Analogous correlation analyses for the FDT revealed no significant results: $r_s < -.55$, $p > .10$).

Lateralized Stimulus Detection: (2) Response Criterion

The four-way ANOVA for criterion *C* revealed a significant main effect for belief group [$F(1, 35) = 11.12$, $p = .002$], indicating that believers' criterion was lower than skeptics' (see Figure 2B). The two-way interaction between belief group and substance group was as predicted, but significant only at the one-tailed level [$F(1, 35) = 2,98$, $p < .05$]. In more detail, believers' criterion was lower than the one of skeptics in the placebo group ($p = .006$), but comparable between belief groups in the levodopa group ($p > .10$). Moreover, skeptics' ($p = .38$) and believers' ($p = .13$) criterions were comparable in the levodopa and placebo groups. No other main effects or interactions were significant (all *F* values ≤ 2.28, corresponding *p* values ≥ .14).

Correlation between the *C* values and raw scores on the ASGS revealed a negative association between these parameters for skeptics in the placebo group and exclusively with respect to LVF/RH stimulations in the LDT ($r_s = -.68$, $p = .029$; see Figure 3B). For believers in the placebo group, ASGS raw scores were significantly positively correlated to

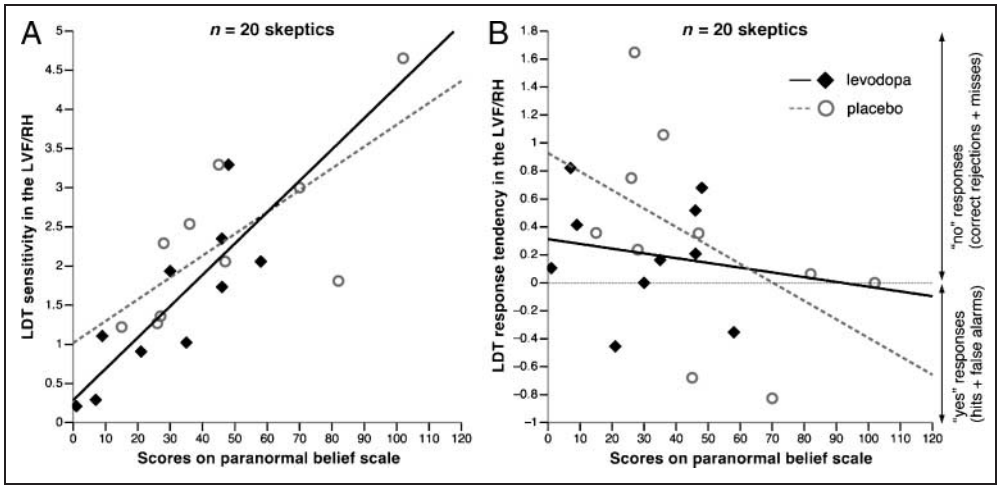

Figure 3. (A) Spearman correlation between skeptics' LVF/RH sensitivity for lexical decisions and paranormal belief scores for the two substance groups separately. No comparable correlation pattern was found for RVF/LH stimulations. (B) Analogous correlation as in A, but for the response criterion *C*.

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C values regarding RVF/LH stimulations in the FDT ($r_s = .63$, $p = .049$).

Lateralized Stimulus Detection: (3) Reaction Time Analyses

The three-way ANOVA on RT indices revealed no significant main effects or interactions [$F(1, 35) < 0.87, p > .36$].

Correlation analyses in the two belief groups between the RT index score in the two decision tasks and participants' raw scores on the ASGS revealed that increasing ASGS scores were negatively correlated to the RT laterality index in skeptics in the levodopa group in both the FDT ($r_s = -.69$, $p = .026$) and marginally significantly the LDT task ($r_s = -.62$, $p = .056$), again indicating an association between paranormal belief and attenuated LH superiority.

DISCUSSION

Healthy participants preselected for their attitudes toward paranormal phenomena were administered two lateralized decision tasks in a double-blind, levodopa, placebo-controlled between-subject design. We aimed to investigate relationships between increased DA availability, the personality trait paranormal belief (notably based on self-perceived own paranormal abilities) and hemisphere-specific signal detection performance. "Signal" was defined here as a meaningful constellation of verbal or facial elements against a "noisy," meaningless configuration of the same elements. We set out to test two main hypotheses concerning the influence of DA on perceptual decisions, that is, decreased sensitivity (lower SNR) and reduced response criterion. In addition, we hypothesized an accentuation of these predicted effects in the believer group and prominently so for RH processing.

On a methodological note, we emphasize that a genuine double-blind procedure could be realized in the present study; neither believers nor skeptics could reliably guess the type of substance they did ingest nor were there any conspicuous behavioral signs that would have informed the experimenter about the type of pharmacological treatment a particular participant had received.

Perceptual Sensitivity: d'

In line with our hypothesis, participants having received levodopa—irrespective of paranormal belief, task, and visual field/hemispheres—had generally *lower* sensitivities than participants having received placebo. These results indicate that the notion of a general enhancement of the SNR by DA (Seamans & Yang, 2004; Spitzer, 1997; Cohen & Servan-Schreiber, 1993) may have to be revised. At least in our two classical decision tasks, a *decrease* rather than an increase in sensitivity was apparent. We interpret this reduced perceptual sensitivity caused by levodopa as a consequence of an increase in "internal noise" (Kapur, 2003) that may have interfered with the sensory input.

However, the pharmacological treatment per se was not related to overall decision performance. The lower sensitivity in the levodopa than placebo group was dependent on participants' paranormal belief. Links between the emergence of paranormal belief and the DA system have been suggested (Brugger & Graves, 1997a) and tested (Mohr et al., 2004; Kumari et al., 1999). Here, contrary to our expectation, a reduced sensitivity in the levodopa as compared to the placebo group was only evident in the skeptics. Previous findings (Mohr, Krummenacher, et al., 2005) would have suggested a modulating effect of DA for both believers and skeptics and an improvement of specifically RVF/LH decisions. This could not be replicated in the present study. One reason for this discrepancy may be differences in the study populations. In the previous study, participants had been recruited randomly from the general population and participants with pronounced paranormal beliefs were excluded. Also, Mohr, Krummenacher et al. (2005) reported only hit rates, whereas the SDT analyses in the present study considered both hits and false alarms. Alternatively, one may speculate that the lack of an effect in the group of believers reflected a plateau effect caused by high cerebral baseline DA levels arguably responsible for low d' values. A single dose of levodopa would then not further have lowered d' values because of a possibly saturated DA receptor activity.

These results further decrease the plausibility that DA generally improves SNR, and instead propose the opposite, in particular, in individuals with a presumably hypodopaminergic system (i.e., the skeptics). A shift in low MI participants' neuropsychological profile toward the psychotic range has repeatedly been shown subsequent to DA agonistic consumption (Mohr et al., 2006; Mohr, Landis, Bracha, Fathi, & Brugger, 2005; Mohr et al., 2004) and seems to be a consistent pattern. Therefore, the present finding is more in accordance with the hypothesis that enhanced dopaminergic transmission produces less constrained firing patterns in mesolimbic neurons. This would generate more internal noise and promote, on the phenomenal level, loosened associations and superstitious beliefs (Shaner, 1999).

Response Criterion *C*

Irrespective of substance, task, and visual field/hemispheres, believers had a lower response criterion than skeptics. This means that they evidenced a tendency to say "yes" rather than "no," or in more general terms, favored a Type I error over a Type II error strategy. Such an inclination is in accordance with previous research with healthy persons endorsing paranormal beliefs (Reed et al., 2008; Tsakanikos & Reed, 2005; Wiseman, Greening, & Smith, 2003; Weinstein & Graves, 2002; Brugger & Graves, 1997b). Although a reduced criterion may be adaptive in detecting real associations and develop novel links between concepts (Folley & Park, 2005; Folley, Doop, & Park, 2003; Weinstein & Graves,

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2001, 2002; Gianotti et al., 2001; Claridge et al., 1990), it simultaneously bears the risk of false causal attributions and lowers the threshold for hallucinatory perceptual experiences (Bell et al., 2007; Brugger & Graves, 1997b).

This general belief effect interacted with DA administration. More specifically, the modulation of response criterion by paranormal belief was only significant for participants in the placebo group. This is in contrast to the sensitivity findings and indicates a balancing effect of levodopa; believers' criterion turned more conservative and skeptics' slightly looser. This interaction effect further supports the proposed links between a participant's baseline dopaminergic activity, and the emergence and maintenance of paranormal ideation. It is also compatible with the finding that, in believers, compensation from higher than normal levels of dopaminergic activity may contribute to psychosis protection (Mohr et al., 2004).

There is evidence both from studies with animals (Arnsten, 1997; Arnsten, Cai, Steere, & Goldman-Rakic, 1995; Williams & Goldman-Rakic, 1995; Arnsten, Cai, Murphy, & Goldman-Rakic, 1994) and humans (Mehta et al., 2000) that with respect to a specific task or task demands (e.g., Floresco & Magyar, 2006) dopaminergic actions might follow the trajectory of an inverted U-shape function, with an improvement of cognitive performance from low to medium doses, but a decline from medium to high doses (Goto, Otani, & Grace, 2007). Applying this idea to the present results, it could be speculated that believers already have a high baseline DA activity, which, when further stimulated by an additional levodopa supplementation, results in a reversal of performance.

Although these conjectures may be promising, caution has to be expressed with regard to the possibly weakest point of the present study, that is, use of a between-subject design. Not only did we have to deal with two different baselines in behavioral performance but also with potentially different baselines in DA responsivity (see Mehta (2002) for the importance of initial physiological states or baseline values). No doubt that future research in DA effects on signal detection and their modulation by paranormal belief must employ a within-subject design, even at the cost of running into problems of learning (Gescheider, 1997) and confounding effects of motivational demands. In order to trace participants at a point of the abovementioned hypothesized inverted U-curve, in future within-subject experiments, baseline assessment (e.g., Muller, von Cramon, & Pollmann, 1998) should not only include cognitive measures but also direct serum or spinal DA metabolic markers such as homovanillin acid (HVA).

Laterality Aspects of Perceptual Sensitivity and Response Criterion

The visual field main effects in the two lateralized tasks confirm the RVF/LH superiority for lexical decisions (Hugdahl, 2000; Regard et al., 1985; Graves, 1983) and a similar (although not statistically significant) superiority of the RH for face detections (Heider & Groner, 1996). This is in line with previous reports showing that RH dominance for face recognition is less pronounced than LH dominance for lexical decisions (e.g., Leehey & Cahn, 1979). This may be due to verbal strategies used by some participants for face recognition leading to activation of LH processes.

With respect to hemispheric processing of verbal material, we found a strikingly different pattern of results for the two belief groups. Interestingly, no lexical decision laterality effects emerged for those participants who claimed to have paranormal experiences and abilities in everyday life. In contrast, in the skeptics, paranormal belief was highly positively correlated in both substance groups to detection sensitivity for words presented to LVF. In other words, as long as paranormal belief remains within a modest range, RH linguistic capacity increases with increasing belief. This is exactly what has been described in numerous previous experiments (e.g., Weinstein & Graves, 2001; Leonhard & Brugger, 1998; Brugger, Regard, et al., 1993) including one recent study that employed an identical LDT paradigm (but no facial decisions, no signal detection analysis, and no preselection with respect to belief groups; Mohr, Krummenacher, et al., 2005).

We have previously argued (Brugger & Mohr, 2008) that the association between paranormal belief and RH linguistic competence may be crucial for an understanding of any laterality aspects of psychotic symptoms. Similar to the situation in acute schizophrenia (Crow, 1997), there seems to be a breakdown of the regular LH dominance for language in extreme paranormal believers whose belief is notably based on apparently paranormal experiences. Up to a certain degree, RH participation in verbal tasks may foster creative thinking, but an overreliance on the less focused associative processing characteristics of the RH may bring about undue claims about perceptual and inferential thoughts. We note that not only skeptics' lexical decision *sensitivity* in the LVF/RH was correlated to paranormal belief but also their tendency to favor "yes" over "no" responses. The shift in the response criterion was, however, confined to the placebo group. Thus, again within the moderate range of paranormal ideation typical for unselected participants, the higher the belief, the more liberal the response criterion based on verbal information displayed in LVF.

Divided visual field performance did not interact substantially with levodopa administration. This may cast doubt on theories that have inconsistently and even antithetically proposed hemispheric asymmetries in the responsivity to dopaminergic treatment. (e.g., Bracha et al., 1993; Bracha, 1989 for RH > LH, but see Reynolds, 1983 for opposite predictions based on a postmortem investigation). Previous inconsistencies in this admittedly controversial clinical literature may have been due to (1) differences in illness duration (acute vs. chronic), (2) medication effects, and/or (3) methodological differences (e.g., behavioral paradigms vs. receptor density determinations).

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The influence of DA may be more marked in the domain of verbal learning (e.g., Breitenstein et al., 2006), and our simple detection tasks may not have been ideal in uncovering differential hemispheric responses to a single dose of levodopa. Rather, indirect evidence for a modulation of laterality patterns by L-dopa comes from the observation that most of the correlations between hemifield performances and paranormal belief were only significant in the placebo group. An exception is the association of belief and the laterality index based on RTs of correct (lexical and facial) decisions (in disfavor of an LH superiority). This was exclusively present for participants (notably skeptics) in the levodopa group. We tentatively conclude that the effects of DA on lateralized performance, if present at all, may target consolidation and motor output processes, rather than the low-level perceptual side of signal detection.

Further Issues

The personality-dependent pharmacological effects described in the present report highlight the need of taking individual personality and capacity differences into account (Mehta, 2002). When ignored, these could obscure meaningful correlations and blur subgroup differences in task performance (White, Lott, & de Wit, 2006; Mohr, Krummenacher, et al., 2005; Mohr, Landis, et al., 2005; Kosslyn et al., 2002; Mattay et al., 2000; Mehta et al., 2000; Kimberg, D'Esposito, & Farah, 1997; Fleming, Bigelow, Weinberger, & Goldberg, 1995). Furthermore, as Hassler and Thadewald (2003) pointed out, pooling data from heterogeneous samples bears the risk to produce misleading results due to "mean value artifacts" (see also the recent illustration by Hadzi-Pavlovic (2007). One source of individual variability in DA responsiveness may be genetically determined (Goldberg et al., 2003; Egan et al., 2001; Weinberger et al., 2001), and potential interactions between such genetic predispositions and an individual's attitude toward the paranormal are currently explored (Raz, Hines, Fossella, & Castro, 2008).

As to the modulation of performance by positive schizotypal personality, we may mention previous findings communicated in the psychiatric literature. It was argued that, contrasted to patients with schizophrenia, individuals with schizotypal personality disorder might have an attenuated risk for psychosis and functional impairments because of a more efficient fronto-cortical buffering of subcortical dopaminergic tone (Koenigsberg et al., 2001; Kirrane et al., 2000; for a similar view with respect to healthy participants' MI and paranormal belief, see Mohr et al., 2004).

General Implications

The main findings of the present study could have implications for the development of novel pharmacotherapeutic treatment strategies for cognitive neuropsychiatric dysfunction. As Floresco and Magyar (2006) pointed out, dopaminergic agents must take into account both the specific types of function that are impaired in patients and the beneficial or deleterious effects that these drugs may have on different cognitive functions.

Further research on the specific DA receptor mechanism that contribute to different types of neuropsychological functions is thus likely to facilitate the development of more selective and effective treatments for specific domains of cognitive dysfunction. To further advance this line of research, it would be challenging to focus more on the specificity of dopaminergic activity by analyzing the effects of (1) dose–response associations, (2) repeated dose administration, and (3) DA antagonists. (4) Monitoring receptor activity in a within-subject design with ligand-PET methodologies may likewise be indispensable.

Apart from their clinical relevance, our findings may have broadest implications for general cognitive psychology and applied psychology. Over the past decade, evidence has been accumulated that paranormal belief is an important personality dimension that should never be left unassessed in the framework of tasks that investigate the detection of signals in noise and the subsequent processes of deductive reasoning. Paranormal ideation may profoundly modulate recognition memory, pain evaluation, social behavior (e.g., reward sensitivity), risk assessments, and general decision making.

Acknowledgments

We thank Marianne Wackermann for blood serum preparation, Lotti Batschelet and the nurses on floor HAL C of the Department of Neurology for the collection of, and Marc Fathi (Geneva) for the analysis of, the blood samples. This research was funded by a grant from the "Institut für Grenzgebiete der Psychologie und Psychohygiene," Freiburg i. Br., Germany (#690610) to P. B. and C. M. Preparation of this report was further supported by a grant from the OPO Stiftung to the first author. Parts of this work were presented at the FENS 2002 (Abstr. vol 1, A074.14).

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