



Planning impairments in schizophrenia: Specificity, task independence and functional relevance

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ARTICLE INFO

Article history:

Received 14 December 2012

Received in revised form 20 May 2013

Accepted 4 June 2013

Available online 1 July 2013

Keywords:

Schizophrenia

Depression

Planning ability

Neuropsychological assessment

Cognitive impairment

Functional outcome

ABSTRACT

The present study investigated the specificity of planning impairments in schizophrenia compared to unipolar major depression. Multiple measures of planning ability were employed to assess the task independence of a planning deficit. Furthermore, the predictive power of planning ability with regard to functional outcome was analyzed. A total of 80 participants completed a comprehensive neuropsychological assessment with an emphasis on executive functions and planning ability. The sample consisted of 28 patients with schizophrenia, 28 patients with depression and 24 healthy controls. Both patient groups were impaired on measures of attention, working memory and planning, but only planning ability differentiated between patient groups. The deficit was evident across different measures of planning ability and was the best overall predictor of functional outcome. These results provide evidence for the relative specificity of a planning deficit in schizophrenia and show that the deficit is not task-specific but likely affects central cognitive control processes critical for planned behavior. The observed relation to functional outcome supports the clinical relevance of planning ability.

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1. Introduction

Schizophrenia affects a wide range of cognitive abilities, such as learning, memory, verbal ability and executive functions (Heinrichs and Zakzanis, 1998). Executive functions in general have been shown to be predictive of functional outcome in schizophrenia (Green et al., 2000; Velligan et al., 2000) and the present article particularly focuses on the role of planning ability, which is integral to many everyday activities (Miller et al., 1960). Neuropsychological studies consistently show a deficit of patients in standardized planning tasks, and planning impairments in schizophrenia have also been described in detailed analyses of activities of daily living (Semkovska et al., 2004; Seter et al., 2011). However, planning has arguably received less attention than other domains of executive functioning in schizophrenia (Reichenberg and Harvey, 2007). In particular, there is comparatively little evidence on (1) how specific the planning deficit is relative to other neurologic and psychiatric patient groups and domains of executive functioning, (2) to what extent the observed deficit depends on the tasks used to measure it, and (3) how predictive it is for functional outcome. To

contribute towards answering these questions we compared the performance of patients with schizophrenia, unipolar depression and a healthy control group using a neuropsychological test battery including multiple measures of planning ability. To our knowledge this is the first study to combine these factors for investigating the relative specificity, task independence and functional relevance of a planning deficit in schizophrenia.

1.1. Specificity of a planning deficit in schizophrenia

Neuropsychological, experimental, and neurophysiological studies have shown a pervasive planning deficit at all stages of schizophrenia, independent of chronicity and medication (e.g., Morris et al., 1995; Pantelis et al., 1997; Hutton et al., 1998; Rushe et al., 1999; Marczewski et al., 2001; Chan et al., 2004). The deficit shows a replicable pattern in standard planning tasks such as the Tower of London (Norman and Shallice, 1986) and its variants. Initial planning times are usually comparable to those of healthy control participants, while in addition to being more error prone, plan execution is usually slower independent of psychomotor retardation (Morris et al., 1995; Pantelis et al., 1997). Several authors argue that impaired plan execution may nevertheless be a result of difficulties at the initial planning stage, possibly due to a tendency towards responding before the plan is fully formed (e.g., Hilti et al., 2010; Hutton et al., 1998; Morris, 1995).

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Furthermore, several studies found an effect of task complexity, whereby the performance of patients with schizophrenia degrades disproportionately relative to healthy control participants as the number of moves required increases (e.g., Morris et al., 1995; Marczewski et al., 2001; Hilti et al., 2010).

However, as schizophrenia involves a broad range of cognitive deficits it is not clear to what extent an impairment of planning ability is disorder- or domain-specific. Additionally, as most recent research employs a single planning paradigm (the Tower of London and its variants) it also remains an open issue to what extent the observed deficit is task-specific rather than construct-specific. To address these questions, studies would have to include patient groups other than schizophrenia, multiple measures of planning ability, and a range of cognitive tests covering other ability domains.

While numerous studies comparing the neuropsychological profile of patients with schizophrenia to other patient groups exist, most do either not include planning ability or no psychiatric comparison group and none employ multiple measures of planning ability. Studies comparing the planning performance of patients with schizophrenia to patients with neurological disorders (e.g., traumatic brain injury) found that patients with schizophrenia show qualitatively similar impairments to those patients with frontal lesions (Chan et al., 2004; Pantelis et al., 1997; Rushe et al., 1999), supporting the role of a frontostriatal deficit as one component of schizophrenia. One study including patients with bipolar mania as a psychiatric comparison group (Badcock et al., 2005) found no difference in planning accuracy between those two groups. To our knowledge a comparison of planning ability of patients with schizophrenia and any type of depression (unipolar or bipolar, psychotic or non-psychotic) has so far not been conducted.

One possible neurocognitive explanation for a specific planning deficit in schizophrenia is an inhibition deficit at the level of action selection by the supervisory attentional system (Frith, 1987; Norman and Shallice, 1986; Robbins, 1990), inducing patients to act prematurely before planning is completed. However, evidence for this hypothesis is equivocal, as for example Marczewski et al. (2001) showed that patients were able to inhibit perceptually cued but incorrect moves just as well as healthy control participants. Alternatively, Cohen and Servan-Schreiber (1992) proposed a computational theory addressing a range cognitive deficits in schizophrenia based on the *internal representation of context*, which they associate with the regulation of dopaminergic activity in prefrontal cortex. Considering context information beyond the immediate stimulus given – such as task rules, instructions or the results of previous actions and cognitive steps – is essential for planning and problem-solving tasks. An impaired use of such context information therefore represents a plausible explanation for the corresponding deficits observed in schizophrenia (Bustini et al., 1999).

Furthermore, this would explain why planning ability is less affected in psychiatric disorders where the internal representation of context is not as strongly impaired. We therefore selected patients with unipolar depression as a comparison group. Patients with bipolar disorder or depression with psychotic episodes were not included, as these disorders may partly share etiology and therefore neurocognitive impairments with schizophrenia (Hill et al., 2009). While we expected a general deficit in executive functioning in major depression (Austin et al., 2001), we did not expect planning ability to be disproportionately affected, as the representation of contextual information is not known to be specifically impaired in this disorder.

In order to show the specificity of a planning deficit in schizophrenia relative to other domains of cognitive functioning, we administered a battery of neuropsychological tests that covered five of the dimensions of executive functioning identified by Royall et al. (2002): planning, rule finding, working memory, attention and inhibition. We expected a generally lower level of performance of both patient groups compared to the healthy control group, and a disproportionate deficit for planning ability in schizophrenia.

1.2. Task independence

Additionally, we investigated to what extent the planning deficit is evident independent of the measurement method. Most studies of planning ability in schizophrenia employed just a single measure of planning ability, usually the Tower of London (Shallice, 1982) or one of its variants. This limits the generalizability of the findings, as any deficit observed may be due to incidental task-specific characteristics rather than individual differences with respect to the underlying construct of planning ability. In particular, the Tower of London is an abstract move-planning problem that has been shown to partially depend on motor control (Morris et al., 1995; Pantelis et al., 1997) and visuo-spatial working memory (Rushe et al., 1999). We therefore decided to include two alternative planning tests to investigate the task independence of the deficit. The tasks chosen were specifically developed for the ecologically valid assessment of planning ability. The Zoo Map test (Wilson, 2000) requires planning a route for visiting a zoo taking into account certain constraints, while Plan-a-Day (Holt et al., 2011) is a computer-based activity scheduling task with work place semantics. We expected that planning performance would be similarly impaired across different measures, supporting a deficit at the construct level rather than just a task-specific impairment.

1.3. Functional relevance of planning

Planning impairments in schizophrenia have been described in detailed analyses of activities of daily living (Semkovska et al., 2004; Seter et al., 2011) and there also is initial evidence for the association of planning performance in neuropsychological assessment and functional outcome (Holt et al., 2011; Wykes et al., 2012). Planning ability may therefore represent a useful bridge construct, linking basic neurocognition and real-world functioning. Accordingly, we expected that planning deficits would significantly predict measures of functional outcome.

2. Method

2.1. Participants

Patients were recruited at the outpatient unit of a psychiatric hospital in Baden-Baden, Germany. The schizophrenia sample consisted of 28 patients with a DSM-IV diagnosis of paranoid schizophrenia ($n = 24$) or schizoaffective disorder ($n = 4$). The depression sample included 28 patients with a DSM-IV diagnosis of recurrent major depressive disorder ($n = 22$) or a single major depressive episode ($n = 6$). All patients were outpatients in a post-acute phase of the illness. Exclusion criteria were (1) presence of psychiatric disorders other than those listed above, (2) evidence of significant substance abuse three months prior to the study, (3) a history of psychotic symptoms in the depression group, (4) evidence of clinically significant organic or neurological disorders. A healthy comparison group ($n = 24$) with no known history of psychiatric treatment was recruited from hospital support staff. All groups were matched for age, $F(2,77) = 0.41$, $p = .67$, and years of formal education, $F(2,77) = 0.87$, $p = .42$, patient groups were also matched for premorbid IQ, $F(1,54) = 0.01$, $p = .77$, see Table 1. Participants gave written informed consent prior to taking part in the study.

Clinical assessment included the Positive and Negative Syndrome Scale (PANSS; Kay et al., 1987) and the Beck Depression Inventory (BDI; Beck et al., 1988). In the schizophrenia sample, 27 patients were treated with atypical antipsychotics, one patient received no pharmacological treatment at the time of testing. In the depression group, 18 patients were treated with SSRIs, four received other antidepressant medication, and six received no pharmacological treatment.

Table 1
Demographic and clinical characteristics of the sample.

	Healthy Control (HC) n = 24	Schizophrenia (SZ) n = 28	Depression (DP) n = 28
<i>Demographics</i>			
Age	32.88 (7.80)	33.11 (8.47)	34.75 (8.66)
Range	20–50	18–50	18–49
Sex			
Female	41.7%	35.7%	64.3%
Male	58.3%	64.3%	35.7%
Years of education	14.13 (3.17)	14.18 (3.27)	13.29 (1.82)
MWT-B	30.75 (2.58)	28.43 (3.42)	28.36 (4.31)
<i>Clinical variables</i>			
PANSS Total		80.11 (15.01)	
PANSS Positive		14.64 (4.46)	
PANSS Negative		25.0 (5.88)	
BDI			26.50 (8.34)
GAF		33.32 (12.86)	44.08 (12.17)

Note. Unless indicated otherwise, values represent means with standard deviations in parentheses. MWT-B = Mehrfachwahl-Wortschatz-Intelligenztest (vocabulary based test of crystallized intelligence).

2.2. Neuropsychological assessment

Planning ability was assessed with the Tower of London (Tucha and Lange, 2004), the Zoo-Map task from the Behavioral Assessment of the Dysexecutive Syndrome (BADS; Wilson, 2000), and the computer-based Plan-a-Day test (Holt et al., 2011). The Zoo-Map task requires planning a route for visiting a zoo, while Plan-a-Day requires scheduling activities in a simulated work setting. Cognitive assessments furthermore included Digit Span and Letter–Number–Sequencing tasks from the Wechsler Adult Intelligence Scale (von Aster et al., 2006), the d2 attention performance test (Brickenkamp, 2002), a computer-based color-word Stroop task (based on Markela-Lerenc et al., 2006), and a computer-based version of the Wisconsin Card Sorting Task (cf. Heaton et al., 1993).

Everyday functioning was assessed using the Global Assessment of Functioning (GAF; American Psychiatric Association, 2000) and the Dysexecutive Questionnaire (DEX) of self-reported executive difficulties in everyday life (Wilson, 2000). As a behavioral measure of functional outcome, we recorded the number of days patients were medically certified as unable to work due to their respective psychiatric disorder during a six month period following the cognitive assessment. The judgment of “inability to work” is carried out as a regular part of routine appointments by the treating physician and represents a legally defined and economically relevant public health outcome variable (cf. Wittchen and Jacobi, 2005). The decision is legally binding for employers and health insurance purposes and implies mandatory sick leave. The central decision criteria are (a) whether patients are capable

Table 2
Neuropsychological test performance by dimension of executive functioning.

Neuropsychological tests	HC	SZ	DP
<i>Planning</i>			
Tower of London	16.75 (1.65)	14.61 (1.79)	16.18 (1.59)
Zoo-Map	6.96 (2.07)	4.71 (2.89)	6.00 (2.60)
Plan-a-Day	34.93 (14.67)	45.69 (15.42)	41.77 (16.89)
<i>Working Memory</i>			
Digit Span Forward	11.46 (1.64)	9.32 (2.06)	9.18 (2.06)
Digit Span Backward	8.42 (2.39)	6.43 (2.20)	6.50 (1.90)
Letter–Number–Sequencing	12.83 (2.51)	10.07 (2.57)	10.57 (2.53)
Attention (d2)	197.63 (48.27)	157.75 (42.62)	163.21 (53.49)
Response Inhibition (Stroop)	76.00 (81.32)	65.68 (75.70)	76.38 (79.97)
Rule Finding (WCST)	5.82 (0.61)	5.07 (1.70)	5.43 (1.29)

Note. Scores: Tower of London—problems solved with minimum moves (0–20); Zoo-Map—profile score (0–8); Plan-a-Day—average execution time in seconds; d2—concentration performance score; WCST—number of categories completed; Stroop—interference in ms.

of carrying out their respective work without (b) thereby compromising their recovery prospects (Volume V of the German Social Code, 2003).

2.3. Statistical analysis

Cognitive ability scores were converted to z-scores relative to the control group, limiting extreme values to a maximum z-score of $+/-4$. Two missing values ($<0.03\%$ of all data) were replaced with group means. Summary scores for the different domains of executive functioning were calculated when more than one indicator was available. Differences in the cognitive ability profile were tested using MANOVA, followed up by comparisons in single domains using ANOVA. Further post-hoc tests were conducted using the Ryan–Einot–Gabriel–Welsch Q procedure (REGWQ), which provides a good balance of statistical power and control of family-wise error in multiple testing (Howell, 2002). Following the group comparison, a stepwise regression procedure was used to establish which cognitive variables were the best predictors of functional outcome in the patient samples.

3. Results

3.1. Overall neuropsychological profile

The MANOVA indicated clear overall differences between the neuropsychological profiles of the diagnostic groups, $F(10,148) = 4.18$, $p < .001$. A corresponding multiple linear discriminant analysis achieved a classification accuracy of 70.0% across the three groups, 2.09 times the chance level of 33.5%. The global composite score of executive functioning differed significantly between patients and non-patients, but not between patient groups, see Fig. 1 and Table 3.

3.2. Individual dimensions of executive functioning

There were notable differences between groups for planning, working memory and attention, marginal differences ($p = .10$) for rule finding and no statistically significant differences for response inhibition, see Fig. 2 and Table 3. The REGWQ procedure indicated a general difference between patients and non-patients on working-memory and attention, while only the planning score differentiated schizophrenia and depression groups.

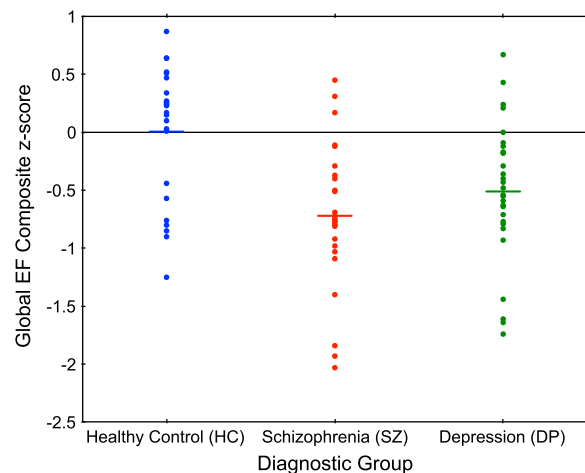


Fig. 1. Global composite score across all domains of executive functioning for each diagnostic group.

Table 3
Results of univariate ANOVAs comparing diagnostic groups on the global composite score, composite scores for each dimension of executive functioning, and individual tests.

Neuropsychological tests	F	df	p	Homogenous subsets ^a
Global EF Composite	9.30	2, 77	<.001	HC > (SZ, DP)
Planning	14.37	2, 77	<.001	HC > DP > SZ
Tower of London	11.61	2, 77	<.001	(HC, DP) > SZ
Zoo-Map	5.03	2, 77	.01	(HC, DP) > (SZ, DP) ^b
Plan-a-Day	3.06	2, 77	.05	(HC, DP) > (SZ, DP) ^b
Working Memory	12.38	2, 77	<.001	HC > (SZ, DP)
Digit Span Forward	10.91	2, 77	<.001	HC > (SZ, DP)
Digit Span Backward	6.86	2, 77	<.01	HC > (SZ, DP)
Letter-Number-Sequencing	8.50	2, 77	<.001	HC > (SZ, DP)
Attention (d2)	5.05	2, 77	.01	HC > (SZ, DP)
Response Inhibition (Stroop)	0.16	2, 77	.85	(HC, SZ, DP)
Rule Finding (WCST)	2.41	2, 77	.10	(HC, SZ, DP) ^c

^a Parentheses indicate homogenous subsets according to the REGWQ procedure with alpha = .05.

^b DP may be grouped with either HC or SZ.

^c Marginally different subsets at $p = .10$: (HC, DP) > (SZ, DP).

3.3. Planning measures

The overall pattern for the planning composite score was reflected in all three subtests, with the healthy comparison group scoring highest, followed by depression and then schizophrenia, see Tables 2 and 3. The Tower of London most clearly separated the schizophrenia group from the other two groups. In addition to the main test scores, we also compared performance on three commonly used planning process variables, aggregated across the three tasks. Corresponding to the literature, we found no marked differences in initial planning time, $F(2,77) = 5.45, p = .58$, but only on accuracy scores, $F(2,77) = 8.46, p < .001$, and marginally on execution time, $F(2,77) = 2.82, p = .07$, see Fig. 3.

3.4. Prediction of functional outcome

Table 4 summarizes descriptive data for the diagnostic groups on the outcome variables. Both patient groups had comparable self-rating of dysexecutive symptoms (DEX) and did not vary significantly on the number of days medically certified as unable to work. The Global Assessment of Functioning was significantly lower for the schizophrenia sample, $F(1,50) = 9.51, p < .01$.

Stepwise regression analysis showed that planning ability was the best single predictor for the Global Assessment of Functioning in both depression and schizophrenia groups, see Table 5. For days unable to work, working memory was a better predictor than planning ability in the depression group ($R^2 = .30$ vs. $R^2 = .12$). Planning was the best predictor for days unable to work in the schizophrenia group, although not to a statistically significant extent. Analyzing both patient groups

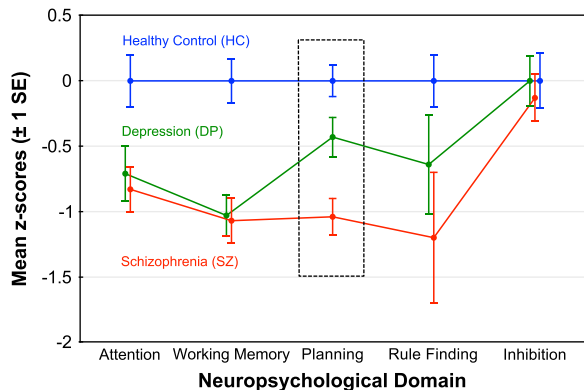


Fig. 2. Neuropsychological profile of diagnostic groups across executive domains standardized relative to the control group.

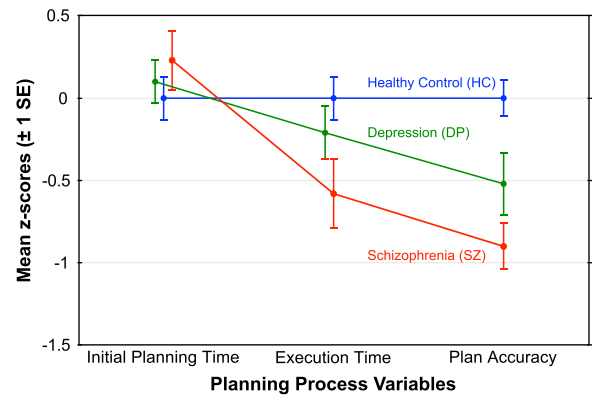


Fig. 3. Planning process variables aggregated over all three planning tests (Tower of London, Zoo Map, Plan-a-Day) by diagnostic group.

jointly yielded planning as the strongest single predictor. For all regression models reported, no additional predictor would have significantly improved the model. No facet of executive functioning was a statistically significant predictor of the DEX self-rating.

4. Discussion

While both patient groups showed a deficit in planning ability relative to the control group, the deficit was markedly stronger for the schizophrenia group. On all other dimensions of executive functioning assessed in this study both patient groups scored comparably. Although impairments of attention and working memory were notable in both groups they did not differentiate between schizophrenia and depression groups. These findings support the relative specificity of a planning deficit in schizophrenia against a background of a more general cognitive deficit. This extends existing studies on planning ability in schizophrenia that have shown replicable planning deficits, but did not include other patient groups, multiple measures of planning ability and additional measures of executive functions.

4.1. Task independence

Extending existing research, the present study shows that the planning deficit is not tied to a particular neuropsychological test, but evident across a range of measures of planning ability with different domain-specific demands, e.g., the Tower of London with a strong visuo-spatial component (Rushe et al., 1999) or the Plan-a-Day test which predominantly covers the verbal-temporal domain (Holt et al., 2011). This supports the notion of a construct-level deficit affecting supramodal cognitive control processes involved in planning tasks, rather than just a narrow task- or modality-specific deficit (cf. Rushe et al., 1999).

Table 4
Measures of functional outcome for the diagnostic groups.

	Healthy control (HC)	Schizophrenia (SZ)	Depression (DP)
	n = 24	n = 28	n = 28
GAF		33.32 (12.86)	44.08 (12.17)
DEX	16.63 (7.37)	27.11 (12.71)	30.89 (9.59)
Days ^a		70.65 (76.12)	48.20 (67.39)

^a Number of days medically certified as unable to work in the six months following the neuropsychological assessment. For this variable SZ n = 20 and DP n = 20.

Table 5
Best predictors of functional outcome selected from the EF composite dimensions Planning, Working Memory, Attention, Inhibition, and Rule Finding.

Criterion	Group	Predictor ^a	B	R ²	Adj. R ²	F (df)	p
GAF	SZ	Planning	6.81	.14	.11	4.36 (1, 27)	.05
		DP	6.72	.19	.15	5.12 (1, 22)	.03
Days ^b	SZ	Planning	36.44	.11	.06	2.15 (1, 19)	.16
		DP	34.04	.26	.22	6.33 (1, 19)	.02
		SZ + DP	31.40	.13	.11	5.81 (1, 38)	.02

^a Best predictor of this outcome variable determined by backwards regression. In all cases at most one predictor was statistically significant.

^b Number of days medically certified as unable to work in the six months following the neuropsychological assessment.

4.2. Processes underlying impaired planning in schizophrenia

The results for different aspects of the planning process were convergent with the existing literature (e.g., Morris et al., 1995; Bustini et al., 1999; Rushe et al., 1999; Chan et al., 2004): initial planning times were comparable across diagnostic groups for all planning tasks, while deficits were apparent in execution time and accuracy. It has been suggested that the low quality of planning evident in the accuracy scores may be due to an inhibition deficit inducing patients to act prematurely before the plan is complete (cf. Robbins, 1990), but some recent studies are incompatible with this explanation (e.g., Marczewski et al., 2001). Indeed, initial planning times comparable to the control group times may be taken as evidence that this stage of the process is not impaired (e.g., Rushe et al., 1999; Hilti et al., 2010).

The overall pattern of results in this study and similar other studies appears to be consistent with an impairment in the internal representation of context information in schizophrenia, associated with dopaminergic activity in prefrontal cortex (Cohen and Servan-Schreiber, 1992). This would explain why tasks with high demands on processing contextual information – such as planning and problem-solving tasks – are disproportionately affected compared to tasks involving a relatively static context, e.g., sustained attention tasks. The explanation fits with the process data reported above, as difficulties in using and updating contextual information become particularly pertinent during plan execution, resulting in errors and slower execution, whereas the initial planning phase is less affected. Beyond impaired planning ability, this deficit may also explain the increased number of task rule violations and difficulties in rule-finding tasks observed in other studies (Hutton et al., 1998; Bustini et al., 1999).

Furthermore, the impairments observed in patients seem to be stronger when the context to be represented is particularly complex and requires frequent changes and updating. This “complexity hypothesis” is consistent with an effect observed in several studies, where planning impairments increase disproportionately with task complexity (e.g., Morris et al., 1995; Marczewski et al., 2001; Hilti, 2010). The planning deficit may not so much be a narrowly circumscribed problem with simple cognitive “look ahead” but rather a more general deficit in information selection, strategy formation and action monitoring (cf. Burgess et al., 2005), which also fits with its independence from specific assessment tasks reported above. The relatively open nature of planning tasks, i.e., the need to structure a situation and develop a strategy, may make them more sensitive to deficits in this area than other tasks.

4.3. Predicting functional outcome

Regression analyses showed that the planning factor was the best predictor for the Global Assessment of Functioning in both patient groups. It also significantly predicted the number of days patients were medically certified as unable to work for both groups combined, although working memory was a better predictor in the depression group alone. These findings underscore the practical importance of

planning ability, supporting results from studies that have shown the functional importance of planning in naturalistic settings (e.g., Semkowska et al., 2004; Seter et al., 2011; Wykes et al., 2012). These results support the position of planning as a bridge construct between basic neurocognitive functions and real-world functioning.

4.4. Limitations

The use of three indicators for the planning and working memory composite scores may have rendered comparisons with facets based only on one indicator slightly unbalanced. However, results for individual tests, if somewhat less clear cut. In order to separate the method-specific contribution to the effect from the underlying construct even more quantitatively, it would be desirable to repeat this design with a larger sample and apply latent variable modeling techniques (cf. Burgess et al., 2000; Miyake et al., 2000).

Rather than showing a pronounced deficit in schizophrenia, one may conversely read the data as indicating a relatively mild planning deficit in the depression group. This cannot easily be decided by comparing absolute effect sizes across domains, as even standardized effect sizes depend on incidental task-specific factors such as measurement error and reference group variability. We therefore focused on differences between patient groups within domains to reduce these incomensurability problems.

It should be noted that our findings are specific to patients with non-psychotic unipolar depression and might not generalize to patients with bipolar depression or psychotic unipolar depression. Since the latter patient groups tend to show more pronounced cognitive deficits, it would be interesting to investigate whether their planning capacity more closely resembles that of patients with schizophrenia.

The failure of the Stroop task to separate the diagnostic groups was unexpected and may be due to the fact that computer-based single-trial Stroop tasks are known to not always produce increased interference effects in patients with schizophrenia (Henik and Salo, 2004). Similarly, that DEX self-ratings could not be predicted by the test battery supports the hypothesis that self-ratings of executive dysfunction are not always a reliable indicator of objective performance (Medalia and Thysen, 2008).

4.5. Conclusion

The present study confirms a characteristic planning deficit in schizophrenia which is specific relative to other aspects of executive functioning in comparison with unipolar depression. Furthermore, this deficit is present across different measures of planning ability and contributes towards predicting functional outcome. These findings support the role of planning ability as a promising link between basic neurocognition and real-world functioning from an applied clinical as well as a basic research perspective.

Role of funding source

This research was supported by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung), grant number 01GW0639.

Contributors

DH, JW, and SK conceived and designed the study. DH and JW conducted the data collection. DH analyzed the data and wrote the first draft of the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of interest

DH and JF are the authors of a commercially distributed version of the Plan-a-Day test used in this study. All other authors declare that they have no conflicts of interest.

Acknowledgment

We thank Nora Grund for assisting with data collection.

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