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ORIGINAL PAPER

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Intact and deficient feature fusion in schizophrenia

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Abstract In patients with schizophrenia, early as well as late stages of information processing can be deficient. Therefore, it is important to determine the earliest occurrences of aberrant processing since deficits on these stages may cause abnormal processing on later, e. g. cognitive, levels. In order to investigate this issue in the visual domain, we studied one of the most basic feature integration mechanisms, namely feature fusion. Our results indicate that in schizophrenic patients this integration mechanism is qualitatively intact but reveals quantitative impairments that may influence later processing stages.

Key words schizophrenia · backward masking · early visual processing · binding problem · feature fusion

Introduction

We perceive objects of the outer world seemingly without efforts. However, object recognition requires detailed and time consuming analysis on many stages of the visual information processing hierarchy. To cope with the vast number of objects, features of these objects are analyzed separately in different parts of the brain. This parallely processed information has to be bound or *integrated* to create a unified percept.

From the early days of schizophrenia research, it is known that schizophrenic patients reveal binding and integration deficits (Bleuler 1911). Deficits were discovered in high level cognitive tasks and attributed to formal thought and affective disorders. Recent research has shown that schizophrenic patients show processing deficits over a wide range including visual processing (e. g. Yates 1966; Braff and Saccuzzo 1981; Schuck and Lee 1989; Weiner et al. 1990; Rund et al. 1993; Nuechterlein et al. 1994; Slaghuis and Bakker 1995; Green et al. 1994a,b; Slaghuis and Curran 1999; McClure 2001). However, it is not yet known whether visual feature integration deficits in schizophrenia exist on very early information processing levels. Hence, the question arises where and when integration deficits occur in the visual processing hierarchy. It is of particular interest to determine the earliest stages of aberrant processing since these deficits may cause deficient processing on later, i. e. cognitive, stages.

The most well known feature integration mechanism is related to binding of features across domains. For example, the color of an object is processed in different parts of the brain than the shape of this object. However, we do not perceive the color and the shape of an object separately but as a unified object such as a red triangle. How this parallely processed information is bound together is part of the famous binding problem. This is one of the most fiercely debated issues in the cognitive and neuro-sciences (e. g. v. d. Malsburg 1995; Treismann 1998; Roskies 1999). However, feature integration can be much more basic. For example, in feature fusion, features of two rapidly presented objects are combined to one unified percept whereby the two features cannot be individually resolved. A red disc followed by a green one appears as a unique yellow disc (Efron 1967).

To test feature fusion, in a recent study we presented a vernier, i. e. two abutting vertical lines, followed by an anti-vernier (Fig. 1; Brand, Kopmann and Herzog 2004). The offset of the opposite is in the direction anti-vernier to the vernier. All other spatio-temporal parameters are identical to the vernier. If the vernier and the anti-vernier are presented in rapid succession, only one fused

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vernier is perceived. With this constellation, the anti-vernier dominates performance, i. e. the anti-vernier offset influences performance more strongly than the vernier offset. Surprisingly, dominance reverses if the vernier and the anti-vernier are followed by a masking grating, i. e. in this constellation the vernier dominates. These results were first obtained in healthy observers (Herzog, Parish, Koch and Fahle 2003). In a recent contribution, we could show that analogous results hold qualitatively also for schizophrenic patients (Brand, Kopmann and Herzog 2004).

Since backward masking studies have revealed that the timing of information processing rather than the spatial acuity is deficient in schizophrenic patients we investigated the time course of feature fusion in this contribution. In particular, we studied how the dominance of either the vernier or the anti-vernier depends on a) the interstimulus interval (ISI) between anti-vernier and mask and b) the duration of the mask.

The rationale of the experiments is as follows. In the unmasked condition, the anti-vernier dominates whereas in the condition with the masking grating, the preceding vernier dominates. We will change the ISI, i. e. the inter-stimulus-interval between anti-vernier disappearence and grating onset. For very long ISIs, the grating has no impact on performance since the fusion of the vernier and the anti-vernier has terminated before the grating is displayed. This corresponds to the unmasked condition. The anti-vernier dominates. With decreasing ISI, the grating exerts stronger effects and the dominance of the vernier increases. In a second approach, we vary the duration of the grating. The rationale is as before. A 0 ms duration is identical to the unmasked condition. The anti-vernier dominates. With increasing duration, the grating increases its impact and the dominance of the vernier increases.

It is often assumed that the transient system of schizophrenic patients, related to the onset and offset of stimuli, is overactive or otherwise disturbed (e. g. Breitmeyer 1984; Ogmen 1993; Cadenhead et al. 1998; Green et al. 1994a, b; Slaghuis and Curran 1999). It might be that a transient response related to the grating onset affects vernier fusion differently in patients compared to healthy controls, e. g. by a stronger suppression of the anti-vernier which is presented directly before the grating. If the duration of the grating is varied, for example, we may expect a difference in performance between patients and controls for all conditions since the onset of the grating is constant in this experiment.

Methods

General set up

Stimuli were displayed on an Eizo monitor F563-T controlled by a PC. In the experiments, a vertical vernier preceded a vertical anti-vernier. A vertical vernier is composed of two vertical bars that are slightly displaced in the horizontal direction. The anti-vernier had the same spatial parameters as the preceding vernier except for opposite offset direction (see Fig. 1). Vernier and anti-vernier were presented for an identical duration. The sum of both durations is called the total duration. With the exception of the unmasked condition, a grating of 25 elements followed the vernier and the anti-vernier (Fig. 1). The grating elements were aligned verniers, i. e. verniers without horizontal offset. The horizontal distance between elements of the grating was about 200″ (arc sec). Both vernier and grating elements were about 21′ long. The vernier and the central element of the grating appeared always in the middle of the screen. Offset size of the vernier and the anti-vernier was about 75″.

Subjects observed the stimuli from a distance of 2.5 m in a room illuminated dimly by a background light (around 0.5 lx). A pixel comprised about 24″ at this distance. Stimuli were white on a black background. Luminance of stimuli was approximately 80 cd/m^2. Refresh rate was 100 Hz.

The vernier could be offset to the left or right randomly chosen per trial. The anti-vernier was offset in the opposite direction with the same offset size. Because of short presentation times, vernier and anti-vernier were fused to one subjective percept, i. e. only one vernier was perceived. Observers had to discriminate the offset direction of the lower bar of this fused vernier in relation to the upper bar by pressing one of two push buttons. Performance was determined in terms of dominance of the preceding vernier, i. e. we determined the percentage of correct responses according to the vernier. Hence, a value above 50 % indicates dominance of this vernier, a value below 50 % dominance of the anti-vernier, and a performance of 50 % the point of subjective equivalence of vernier and anti-vernier.

Observers

Eleven schizophrenic patients and 11 healthy controls participated. Age, gender, duration of illness, education, chlorpromazine equivalents, means of SAPS (Scale for the assessment of positive symptoms; Andreasen 1984) and means of SANS (Scale for the assessment of negative symptoms; Andreasen 1983), d2 measures (sustained attention; Brickenkamp 1994), and results of the LPS (global cognitive performance; Leistungspruefsystem; Horn 1983) and the MWT (premorbid intelligence; Mehrfachwahl-Wortschatz-Intelligenztest; Lehrl et al. 1991) are listed in Table 1.

Patients as well as healthy controls participated in the tests after signing informed consent. Each observer was informed on the general purpose of the experiment. Subjects were told that they might quit the experiment at any time they wish. Some patients had previously participated in another backward masking study (Herzog, Kopman and Brand 2004).

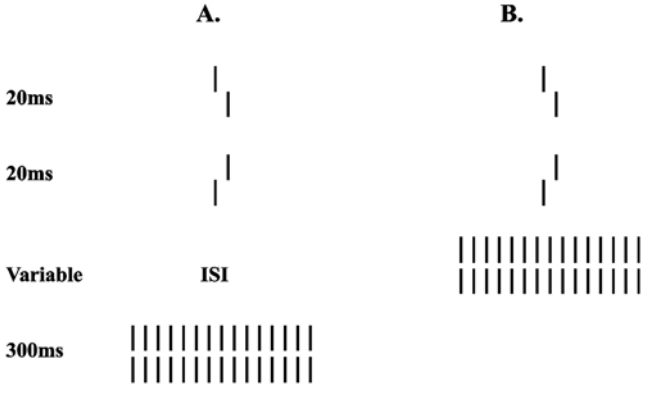

Fig. 1 A vernier was followed by an anti-vernier each presented for a duration of 20 ms. **A** After the two verniers an ISI (Inter-Stimulus-Interval) followed for a variable duration. A grating was presented after the ISI lasting for 300 ms. **B** After the verniers, the grating was displayed immediately. The duration of this grating was varied

Diagnosis and psychopathology

Exclusion criteria for patients were age older than 50 years, diagnosis of a neurological disease, or current substance abuse. Diagnosis was obtained according to DSM-IV relying on a clinical interview, the medical record, and interviews with the hospital staff. For the assessment of the psychopathological condition, the SANS and the SAPS were used. Diagnosis and psychopathological ratings were carried out by an experienced senior psychiatrist (A. B.) within 10 days following the day of testing. Psychopathological rating was based on the symptoms existing in the week preceding the rating. With this method we determined symptoms with a rather close temporal relationship to the testing. All patients were receiving neuroleptic medication taking risperidone, olanzapine, amisulprid, zuclopenthixol, haloperidol, fluphenazine, levomepromazine, clozapine, or flupentixol. Three patients received three of these neuroleptics, another one two. Four patients received biperiden, three patients an additional antidepressant. Three patients were taking benzodiazepines (lorazepam, diazepam, oxazepam). Chlorpromazine equivalents were calculated according to the Agency for Healthcare Research and Quality (Agency for Healthcare Research and Quality 2002).

Procedure

The procedure was divided into three steps. First, we determined the *visual acuity* of patients and healthy controls binocularly by standard tests using number digits as target elements. To participate in the following experiments, observers had to reach a value of 0.8 at least.

In a second step, we adjusted vernier and anti-vernier presentation time in an *unmasked condition*, i. e. no grating followed. For each observer, we determined the individual total duration of vernier and anti-vernier such that a clear dominance of the anti-vernier was found, i. e. performance should be at least below 35 % still avoiding a floor effect. Duration of the vernier was the same as for the anti-vernier. This total duration was used in the following conditions for each observer individually.

In a third step, we determined the influence of either the onset (experiment 1) or the duration of the masking grating (experiment 2).

Experiment 1: Variation of the onset of the grating

After the vernier and the anti-vernier, a grating with 25 elements followed. Between anti-vernier disappearance and grating onset, an ISI was inserted, i. e. a black screen. We assessed performance with various ISIs. The ISI is the interstimulus interval between the temporal offset of the anti-vernier and the onset of the grating. The grating lasted 300 ms.

Experiment 2: Variation of the duration of the grating

In experiment 2, the vernier and the anti-vernier were followed immediately by the grating, the duration of which was varied.

Statistical evaluation

In both experiments, we calculated repeated measures analyses. In experiment 1, we used a within-subjects ISI factor with 7 levels (0, 10, 20, 30, 40, 50 and 60 ms) and a between-subjects group factor. In experiment 2, we used a within-subjects duration factor with 6 levels (10, 20, 30, 50, 100 and 300 ms). All repeated measures analyses were corrected by the Greenhouse-Geisser formula if necessary. In this case, degrees of freedom were truncated to integers (Bortz). For further analysis, we computed ANOVAs, comparing single conditions between groups. Moreover, we calculated individual slopes for both experiments by regression analysis and compared both groups with regard to the slopes by ANOVAs.

Results

Neuropsychological tests

One control subject did not participate in the cognitive tests and one patient did not complete the d2 test. Patients and controls differed only with regard to the d2 attention test ($F[1,18] = 27.9$, $p < 0.0001$). In this test, patients performed substantially poorer than controls (see Table 1).

Feature fusion: no mask

Patients needed a slightly longer total duration (of the vernier and the anti-vernier) in order to obtain a performance level of under 35 % (76.4 vs. 70.9 ms) without statistical significance. In the unmasked condition, patients indicated correctly the offset direction of the preceding vernier in 16.3 %, controls in 13.4 % (see Fig. 2, no mask condition).

Feature fusion: ISI

When the verniers were masked (ISI = 0 ms), patients indicated the vernier offset in 54.2 %, controls in 65.6 % (Fig. 2). The effect of masking was highly significant ($F[1,20] = 189.5$, $p < 0.0001$). A significant interaction ($F[1,20] = 4.8$, $p = 0.04$) was found indicating a steeper increase of the controls.

We compared feature fusion in both groups by using different ISIs between the disappearance of the anti-vernier and the onset of the grating. We assessed performance with ISIs of 0, 10, 20, 30, 40, 50, and 60 ms. 3.9 % (6 values out of 154) of all values were missing since not

Table 1 The number of subjects, gender, age, years of education, results of the cognitive tests (d2, LPS3 and 4, and MWT as t-values) and the disease specific variables such as duration of illness, SANS and SAPS sum scores, and chlorpromazine equivalents are shown. The last column presents the p-values of ANOVAs comparing both groups

	Schizophrenic patients	Healthy controls	p-value
N	11	11	
Gender (f/m)	4/7	6/5	
Age (years)	30.8±10.4	32.2±9.2	ns
Years of education	12.4±2.3	13.8±2.4	ns
Duration of illness	7.5±7.3		
CPZ (mg)	623.6±401.3		
SANS	11.6±3.4		
SAPS	5.0±3.9		
d2	47.1±7.1	62.0±10.4	$p < 0.0001$
MWT	62.1±11.3	66.4±8.7	ns
LPS3	55.8±9.2	59.7±9.5	ns
LPS4	52.5±9.3	59.7±8.0	ns

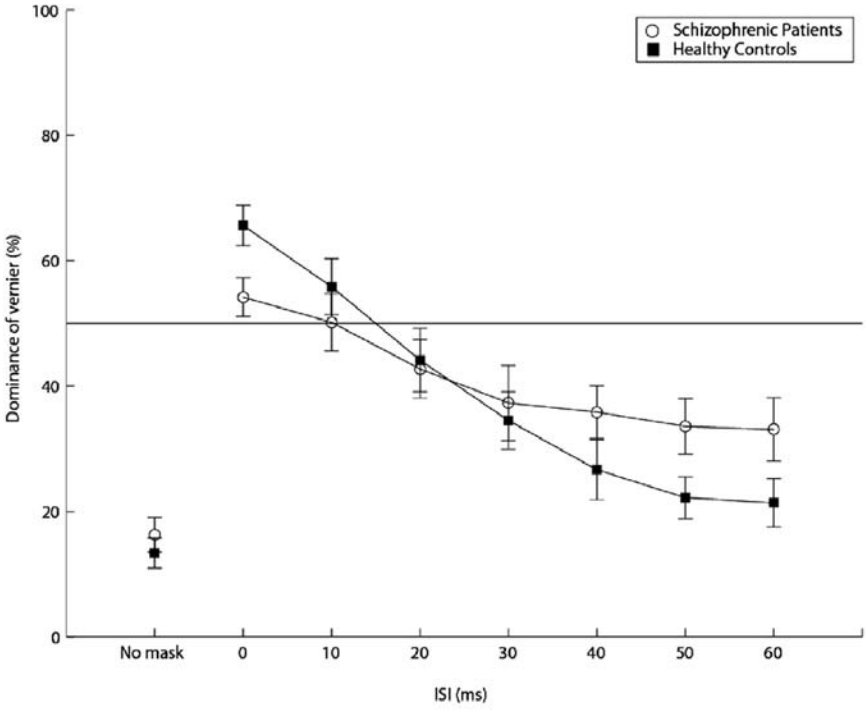

Fig. 2 Performance of schizophrenic patients and healthy controls. The ISI between the temporal offset of the anti-vernier and the onset of the 25 element grating is varied (Fig. 1A). The duration of the grating is always 300 ms. Performance is measured in dominance of the vernier, i. e. the proportion of trials in which the offset of the vernier is indicated correctly (%). Patients and controls show a qualitatively identical performance: the longer the ISI, the lower the dominance of the vernier. The decrease of performance is, however, less steep in schizophrenic patients compared to healthy controls. In the "no mask" condition, only the vernier and anti-vernier were presented

all subjects were measured with each ISI. Missing values were filled in by interpolation.

We did not find a significant group difference ($F[1,20] = 0.24, p > 0.5$). There was, however, a significant ISI effect ($F[2,52] = 35.2$, $p < 0.0001$) and a significant interaction of ISI by group ($F[2,52] = 4.3$, $p = 0.01$). ANOVAs revealed only a significant difference between groups at an ISI of 0 ms ($F[1,20] = 6.5$, $p = 0.02$) and a tendency to significance at the ISI of 50 ms ($F[1,20] = 4.2$, $p = 0.05$). Patients started with 54.2 % at zero ISI and dropped to 33.1 % for an ISI of 60 ms, controls from 65.6 % to 21.4 % respectively (Fig. 2).

We fitted regression lines to the data points. The slopes of the healthy controls differed significantly from those of the patients (–0.78 vs. –0.37, respectively; $F[1,20] = 9.3$, $p = 0.006$).

Feature fusion: duration of the grating

In the second experiment, we compared performance between both groups with regard to different durations of the masking grating. We used durations of 10, 20, 30, 50, 100, and 300 ms.

There was no significant difference between groups but a significant effect of grating duration ($F[2,52] = 43.8$, $p < 0.0001$) and a significant interaction of group by duration ($F[2,52] = 4.46$, $p = 0.01$). Significant group differences were found with durations of 50 ms ($F[1,20] = 8.0$, $p = 0.01$), 100 ms ($F[1,20] = 6.1$, $p = 0.02$), and 300 ms ($F[1,20] = 5.3$, $p = 0.03$). Patients started with 28.1 % for a duration of 10 ms and increased performance to 49.4 % for a 300 ms duration. Control subjects revealed a stranger increase from 24.1 % to 64 % (Fig. 3). Slopes of the healthy controls were substantially higher than those of the patients (0.09 vs. 0.05, respectively; $F[1,20] = 4.7$, $p = 0.04$).

Discussion

In this as well as in a preceding study, we found that the fusion of vernier and anti-vernier in schizophrenic patients follows the same qualitative pattern as it does in healthy controls (Brand et al. 2004). If only vernier and anti-vernier are presented, the anti-vernier dominates. This dominance reverses if a masking grating is presented immediately after the anti-vernier. Hence, patients reveal the same complex characteristics of fusion as do healthy observers.

In the masked condition, it may be that the vernier dominates performance since the anti-vernier is suppressed more strongly by the onset of the following grating. It was often postulated that schizophrenic patients suffer from an overactive, magno-cellular (transient) system that hinders information processing in the parvo-cellular (sustained) system (e. g. Breitmeyer 1984; Ogmen 1993; Cadenhead et al. 1998; Green et al. 1994a,b; Slaghuis and Curran 1999; Schechter, Butler, Silipo, Zemon, Javitt (2002); however, see Keri et al. 2000; Saccuzzo et al. 1996; Slaghuis and Bakker 1995). Hence, suppression of the anti-vernier may be stronger in the patients than in the controls. This effect should be more pronounced for short ISIs and vanish for longer ISIs. However, this result was not found (Fig. 2). Patients show a weaker dominance of the vernier for short ISIs and a weaker dominance of the anti-vernier for longer ISIs compared to controls. If the duration of the mask is var-

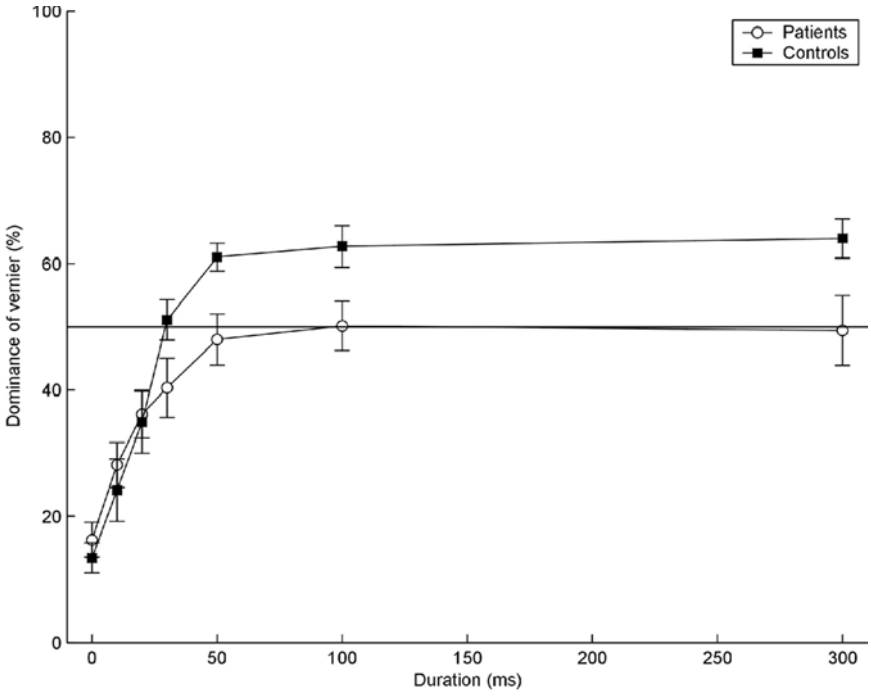

Fig. 3 Performance of schizophrenic patients and healthy controls. The duration of the 25 element grating is varied (for a 0 ms duration no grating was displayed, i. e. the unmasked condition of Fig. 2). Performance is measured in dominance of the vernier, i. e. the proportion of trials in which the offset of the vernier is indicated correctly (%). Patients and controls show a qualitatively comparable performance: the longer the duration of the grating, the higher the dominance of the vernier. The increase is, however, less steep in schizophrenic patients compared to healthy controls

ied, performance of patients and controls seems to be comparable for the first 20 ms (Fig. 3). This result does not corroborate either a hypothesis based on an overactive transient response related to the grating onset suppressing the anti-vernier more strongly than the vernier. Since the grating onset is identical in all conditions of experiment two, patients should show a stronger vernier dominance in all conditions. The deteriorated performance of patients for longer mask durations in experiment two may indicate the involvement of deficient sustained rather than transient responses. However, our results do not rule out an overactive transient system as a cause of masking deficits in schizophrenic patients. For example, it might be that an overactive transient system impairs vernier and anti-vernier processing similarly yielding more shallow slopes of masking functions compared with controls. Another possibility is that an overactive transient system affects directly the fusion mechanism (see below).

Whereas the qualitative pattern of schizophrenic patients appears to be comparable to healthy controls, it seems that quantitatively schizophrenic patients reveal a less pronounced reversal of dominance. In both experiments, healthy observers show a steeper masking function (decreasing with longer ISIs and increasing with longer durations) than schizophrenic patients with more shallow slopes. In experiment two, healthy subjects reach the reversal point (50 %) for shorter durations than schizophrenic patients who only touch it rather than cross it. These quantitative differences cannot be caused by an overall affection by the illness for two reasons. First, performance in the unmasked condition was comparable to healthy subjects (16.3 % for patients vs. 13.4 % for healthy subjects). Second, patients show strong reversals of dominance when total durations are individually matched and the temporal proportions of vernier and anti-vernier are varied by keeping the total duration constant (Brand et al. 2004).

It might be that the more shallow slopes of patients occur since the fusion mechanism is less sharply tuned than in controls. For example, healthy observers may have a more pronounced winner take all mechanism that biases the decision more strongly in favor of one of the verniers. In a dynamical system, neural activity of both verniers may mutually inhibit each other. This mechanism might have a stronger gain in healthy controls yielding a faster and stronger suppression of the other vernier.

Whereas feature fusion seems to be qualitatively intact, other low-level integration mechanisms seem to be qualitatively affected in schizophrenia. For example, it could be shown that, in contrast to healthy controls, schizophrenic patients do not show oscillatory masking functions: patients show a rather monotonic increase in performance if ISI is changed whereas healthy controls reveal up and downs (Green, Mintz, Salveson, Nuechterlein, Breitmeyer, Light and Braff 2003; Green, Nuechterlein, Breitmeyer and Mintz 1999). These results were taken as evidence that temporal binding mechanisms are impaired in schizophrenic patients (see also Phillips and Silverstein 2003; Garcia-Toro, Blanco, Gonzales and Salva 2001). These temporal mechanisms are often assumed to be involved in "across domain feature binding" such as binding the color to the shape of one object (feature fusion may be viewed as feature binding in one domain, e. g. a vernier and anti-vernier fused to one vernier).

Whereas feature fusion seems to be qualitatively intact, the more shallow slopes of patients may cause binding problems on later, e. g. across domain feature bind-

ing stages. For example, a less pronounced competition between stimulus features might smear out or damp oscillations. Therefore, it may be that quantitative differences on early stages of visual information give rise to qualitative differences on later processing stages.

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