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Aging and visual motion discrimination in normal adults and schizophrenia patients

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Abstract

Motion perception is impaired in many neuropathological conditions, including schizophrenia. Motion perception also declines in the course of normal aging. In this study, we ask whether aging is an additive factor in the motion-discrimination deficits of schizophrenia patients. We examined motion perception in schizophrenia patients ($n=44$) and non-psychiatric controls ($n=40$) whose ages ranged from 18 to 55. The tasks included velocity discrimination and contrast detection. Thresholds for each of the two tasks were determined for each subject using psychophysical methods. Schizophrenia patients showed significantly increased thresholds (degraded performance) for velocity discrimination compared with the controls. Degraded performance in patients was not related to age. In controls, however, velocity discrimination thresholds were significantly increased beginning by age 45. Performance on a contrast-detection task, which does not require precise discrimination of motion signals, was not significantly affected by age in either group. Aging, even in its early stages, degrades motion discrimination in normal adults. Aging, however, does not adversely affect motion-discrimination deficits in schizophrenia patients through age 55. A similar motion-discrimination deficit in schizophrenia patients and aging normal adults suggests that the mechanisms underlying motion processing in schizophrenia and normal aging may be associated.

Keywords: Schizophrenic; Age; Vision; Velocity; GABA

1. Introduction

Visual motion processing has been studied to explore the neurological underpinnings of eye-tracking dysfunction in schizophrenia (Holzman et al., 1973, 1974; Sweeney et al., 1992; Levy et al., 1993; Friedman et al., 1995; Stuve et al., 1997; Chen et al., 1999a,b,c). Motion processing has also been studied in normal aging (Owsley et al., 1983; Ball and Sekuler, 1986; Gilmore et al., 1992). The effects of aging on motion processing may be relevant to neurodegenerative changes associated with the pathophysiology of schizophrenia.

Perception of visual movement is impaired in schizophrenia (Wertheim et al., 1985; O'Donnell et al., 1996; Stuve et al., 1997; Chen et al., 1999c, 2003a). For example, velocity-discrimination thresholds of schizophrenia patients are significantly higher

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than those of normal controls (Chen et al., 1999b). Schizophrenia patients' performance is not impaired on tasks requiring detection of the presence of a motion target, however (Chen et al., 1999c). Deficient velocity discrimination in schizophrenia implicates impairments in the motion pathway, although the exact neural mechanism responsible for the impairments is yet to be determined.

Normal aging is accompanied by a decline in visual motion processing, including contrast detection of moving gratings (Owsley et al., 1983), detection of direction of moving patterns (Ball and Sekuler, 1986), perception of velocity of moving patterns (Norman et al., 2003), and perception of coherent motion (Trick and Silverman, 1991; Gilmore et al., 1992). Visual detection of stationary targets, in contrast, is less affected by aging (Owsley et al., 1983; Cronin-Golomb et al., 1991).

The role that aging plays in visual motion processing remains to be determined in schizophrenia. The detrimental effects of normal aging on motion perception suggest that the velocity discrimination deficit might be more pronounced in older schizophrenia patients than in younger ones. Alternatively, velocity-discrimination deficits in schizophrenia might not be magnified by the aging process, which would indicate that the underlying processes are not degenerative.

The visual cues that influence velocity discrimination vary as a function of target velocity (McKee et al., 1986; Chen et al., 1998). At slow velocities (e.g. 3.6°/s), the dominant cues come from the target's position. At fast velocities (e.g. 26.6°/s), the dominant cues come from the target's contrast. At intermediate velocities (e.g. 10°/s), however, the dominant cues come from the target's velocity, a motion signal, and non-motion visual signals (position and contrast) are negligible (McKee, 1981; Nakayama and Tyler, 1981; Pasternak, 1987). Thus, performance on a velocity-discrimination task at the intermediate velocity range reflects the integrity of the motion-processing system.

Here, we examined how the process of aging affects motion processing in schizophrenia patients and non-psychiatric controls. Since the dominant mechanisms underlying velocity discrimination depend on the range of the target velocities, we examined velocity discrimination at slow, intermediate, and fast velocities. We also examined how aging affects contrast detection, a control task that employs procedures similar to those used in the velocity-discrimination task. The two-alternative, forced-choice procedure used in both tasks requires subjects to attend to two stimulus presentations separated by a short interval in order to make a correct response in each trial. Both tasks impose comparable and modest attentional demands and cognitive requirements, an important consideration in studies of aging and psychiatric populations. We tested both schizophrenia patients and normal controls, from early adulthood through the sixth decade of life.

2. Materials and methods

2.1. Subjects

Two groups of subjects were included: (1) Schizophrenia patients (SCZ, $n=44$); (2) normal controls (NC, $n=40$). All subjects were screened for substance abuse/dependence within the previous 2 years and for any neurological or ocular disorders. None of the normal controls met DSM-IV criteria for a psychotic condition (lifetime) or for schizotypal, schizoid, or paranoid personality disorder based on a standardized interview (Kendler, 1989). The SCZ patients were outpatients who met DSM-IV criteria for schizophrenia or schizoaffective disorder. Consensus diagnoses were made independently and blind to the experimental results by experienced clinicians based on a review of a standardized interview (Structured Clinical Interview for DSM-IV, Spitzer et al., 1994) conducted by trained interviewers, and an evaluation of all available hospital records. Most SCZ patients were receiving antipsychotic medication (mean daily chlorpromazine dose equivalent: 516 mg; $\sigma=435$ mg (Woods, 2003)): typical antipsychotic, $n=10$; atypical antipsychotic, $n=26$; both typical and atypical, $n=4$; no antipsychotic medication, $n=4$. The average Brief Psychiatric Rating Scale (BPRS) (Overall and Gorham, 1992) score of the SCZ patients was 38.4 ($\sigma=24.9$). The average duration of illness was 14.2 years ($\sigma=8.1$ years), indicating that these were chronically ill patients in various stages of partial remission. Table 1 presents demographic information about the groups. The ages of the subjects ranged

Table 1
Mean (S.D.) demographic characteristics of subjects

Group	Sex[a]	Age (years)	SES[b]	Verbal IQ[c]	Education (years)
Normal control ($n=40$)	M=10 F=30	39.5 (12.3)	2.0 (.64)	104.4 (11.8)	14.7 (2.6)
SCZ ($n=44$)	M=22 F=22	37.2 (7.5)	2.55 (1.02)	102.1 (13.2)	13.8 (2.0)

[a] M: male, F: female.
[b] Socioeconomic status, based on the Hollingshead and Redlich Two-factor Index (Hollingshead, 1965).
[c] Estimated verbal intelligence quotient based on vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981).

from 18 to 55 years. The two groups did not differ significantly in age, socioeconomic status, verbal IQ, or years of education (all P's >0.05). The control group had significantly more females than the SCZ group, which had an equal number of males and females. Written informed consent in accord with the IRB guidelines of McLean Hospital and Harvard University was obtained from all participants before testing.

2.2. Stimulus

In both tasks, the stimulus, a vertical grating that moved horizontally, was displayed on a Macintosh monochrome monitor (frame rate, 70 Hz). The grating had a sinusoidal waveform (spatial frequency: 0.5 cycles/°) of spatial luminance distribution. The grating was presented within a circular window with a diameter of 10° of visual angle. The grating moved either to the left or to the right, which varied randomly from trial to trial. A fixation cross was provided at the center of the screen.

2.3. Procedure

2.3.1. Velocity discrimination

Subjects viewed two sequentially presented moving gratings that differed in velocity and decided which one, the first or the second, moved faster. Within each trial, the stimulus was presented for 300 ms, and the time interval between the two stimuli was 500 ms. After viewing the two gratings, subjects reported their judgments by pressing one of the two designated buttons on the computer keyboard. A new trial began 500 ms after the subject's response was recorded. The initial velocity difference between the two comparison targets was set at 100%. We used a two-alternative forced-choice procedure to determine the velocity discrimination threshold. This procedure was combined with a standard three-down-one-up staircase. In this procedure, the velocity difference in successive trials was adjusted according to the correctness of a subject's responses. Specifically, the velocity difference between two stimuli in a trial was decreased by 5% of the current level if a subject made three consecutive correct responses, and increased by 5% of the current level if the subject made one incorrect response. The experimental session terminated after 12 reversals of staircase directions. The velocity difference levels of all reversals, except for the first, were averaged to produce a threshold (ΔV), which corresponds to an accuracy level equivalent to 79% correct for every subject (Levitt, 1972). The staircase procedure minimizes the experience of failure, an important consideration when testing psychotic patients. Each subject was tested at three base velocities: 3.6°, 10°, and 26.3°/s, corresponding to slow, intermediate, and fast conditions, respectively; thresholds were obtained for all three base velocities.

2.3.2. Contrast detection

The task was to indicate in which of the two temporal intervals (first or second) in a trial the moving target was present. In one interval of each trial, a grating was presented for 300 ms. In the other interval of each trial, a blank screen was presented for 300 ms. The interstimulus interval was 500 ms. After viewing the two intervals, subjects reported their judgments by pressing one of the two designated buttons on the computer keyboard. A new trial began 500 ms after the subject's response was recorded.

The contrast of the gratings was set initially at 1.5%. The level of contrast varied from trial to trial according to the same two-alternative forced-choice staircase method described above (one-up-three-down). Specifically, the contrast level decreased by 5% of the current level if three consecutive correct responses were made, and increased by 5% of the current level if one incorrect response was made. Contrast levels of all reversals except the first were averaged to produce a threshold.

Detailed instructions and adequate practice for each task were administered before formal data collection. All experimental conditions were completed in a single 1-h session. To minimize fatigue and inattention, short breaks were provided during the session.

3. Results

3.1. Velocity discrimination as a function of age

Linear regression analysis indicated that velocity-discrimination thresholds (VDTs) of NC increased significantly as a function of age only in the intermediate velocity condition (10°/s, $r=0.47$, $P=0.002$), not in slow and fast velocity conditions (3.6°/s, $r=0.12$, $P>0.05$; 26.3°/s, $r=0.22$, $P>0.05$). VDTs in SCZ were not significantly correlated with age in any of the velocity conditions (3.6°/s, $r=0.11$, $P>0.05$; 10°/s, $r=0.03$, $P>0.05$; 26.3°/s, $r=0.11$, $P>0.05$). Fig. 1 presents VDTs at 10°/s for individual subjects.

To examine at which ages VDTs were affected, we divided the subjects into four subgroups on the basis of age (18–24 years, 25–34 years, 35–44 years, 45–55 years). Table 2 presents means and standard deviations of VDTs at the three velocity conditions for NC and SCZ according to the age subgroups. The overall

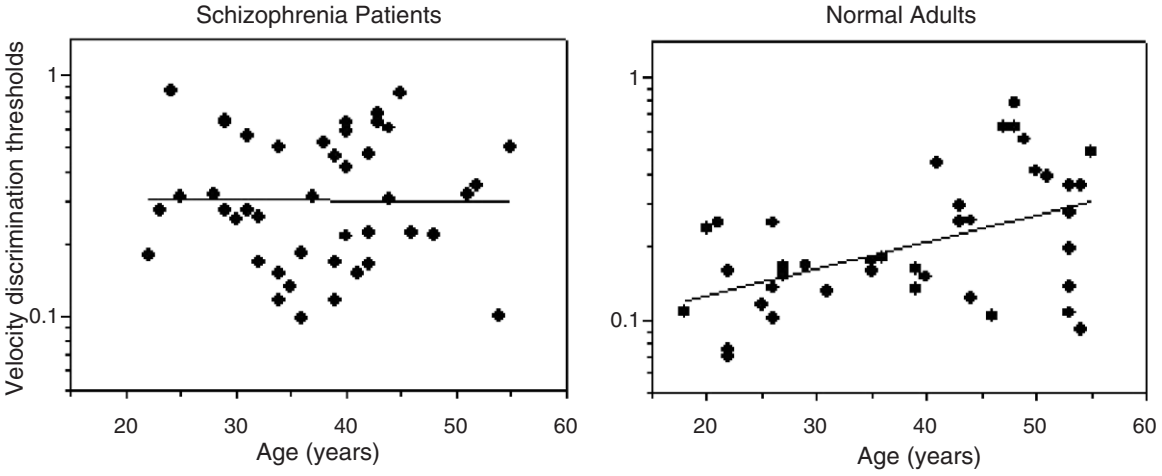

Fig. 1. The left panel is for the SCZ group and the right panel is for the NC group. Each dot represents an individual subject's data. The ordinate of each panel represents velocity-discrimination thresholds on a logarithmic scale. The abscissa denotes age. The regression lines show a significant increase of VDTs with age in NC, but not in SCZ.

model, tested by a 4 (age) × 3 (velocity) × 2 (group) analysis of variance (ANOVA) was significant ($F=8.8$, $df=6$, $P<0.0001$). In the intermediate velocity condition (10°/s), there was a significant effect of age on VDTs in NC ($F=4.5$, $df=3$, $P=0.008$), consistent with the linear regression analysis. There was no significant effect of age for the NC group in the slow (3.6°/s) and fast (26.3°/s) velocity conditions. Duncan's multiple range test (significance criterion set at 0.05) indicated that VDTs of the 45–55-year subgroup of NC were significantly higher than the VDTs of the other NC subgroups. In contrast, VDTs did not differ across the four age subgroups of SCZ ($F=1.06$, $df=3$, $P=0.38$).

The ANOVA showed a significant effect of group ($F=22.31$, $df=1$, $P<0.0001$), indicating significantly elevated VDTs for the SCZ group at 10°/s ($t=2.6$, $df=81$, $P=0.01$) and at 3.8°/s ($t=4.3$, $df=81$, $P<0.0001$). Although SCZ had higher VDTs than NC at the fast velocity (26.3°/s), the group difference did not reach the conventional level for statistical significance ($t=1.8$, $df=81$, $P=0.07$). There was also a significant effect of velocity ($F=14.8$, $df=2$, $P<0.0001$), such that across groups the worst performance occurred in the slow velocity condition.

Because performance in the SCZ group consistently had a higher variance, we assessed whether the slope of the relationship between VDTs and age differed across subgroups of patients (i.e. one group of patients improving with age and another group of patients performing worse with age, resulting in changes in the variance in the SCZ group as a function of age); through a test for homogeneity of errors. According to the methods outlined in McClelland (2000), we plotted the residuals against the predicted values of the regression line of the SCZ group across age. This plot resulted in a non-significant regression line ($r=0.06$, $P>0.05$), indicating that the variance was not heterogeneous in the SCZ group.

3.2. Influence of clinical and gender variables on velocity discrimination

There was no significant correlation between verbal IQ and VDTs at 10 °/s in either NC ($r=-0.17$,

Table 2
Velocity discrimination thresholds at three base velocities: means (standard deviation)

Group ($n=40$)	Normal adults			Group ($n=44$)	Schizophrenia patients		
	3.6°/s	10°/s	26.3°/s		3.6°/s	10°/s	26.3°/s
	0.33 (0.12)	0.25 (0.17)	0.22 (0.19)		0.54 (0.31)	0.37 (0.24)	0.29 (0.15)
Age-subgroup				Age-subgroup			
18–24 ($n=6$)	0.38 (0.09)	0.18 (0.10)	0.18 (0.07)	18–24 ($n=5$)	0.62 (0.45)	0.42 (0.36)	0.24 (0.08)
25–34 ($n=8$)	0.29 (0.11)	0.16 (0.07)	0.23 (0.13)	25–34 ($n=12$)	0.49 (0.37)	0.33 (0.20)	0.27 (0.09)
35–44 ($n=11$)	0.35 (0.13)	0.21 (0.09)	0.17 (0.06)	35–44 ($n=20$)	0.56 (0.25)	0.38 (0.27)	0.34 (0.18)
45–55 ($n=15$)	0.29 (0.13)	0.37 (0.22)	0.30 (0.31)	45–55 ($n=7$)	0.62 (0.21)	0.34 (0.26)	0.23 (0.07)

$P>0.05$) or SCZ ($r=-0.11$, $P>0.05$). VDTs in SCZ were not significantly correlated with either duration of illness ($r=0.13$, $P>0.05$) or BPRS score ($r=0.00$, $P>0.05$). VDTs in patients taking atypical agents (0.43, $\sigma=0.26$, $n=26$) and typical agents (0.41, $\sigma=0.53$, $n=10$) did not significantly differ ($t=0.23$, $df=34$, $P=0.82$). The thresholds for those patients taking both typical and atypical agents ($n=4$) and no antipsychotic medication ($n=4$) were 0.15 ($\sigma=0.11$) and 0.12 ($\sigma=0.17$), respectively. No significant gender differences were found in either NC ($t=0.42$, $df=38$, $P=0.67$) or SCZ ($t=1.03$, $df=42$, $P=0.30$) with respect to VDTs. Although the NC group was made up of 75% females, the slope of the relationship between age and VDTs at 10°/s did not differ between male and female controls ($z=0.28$, $P=0.43$).

3.3. Contrast detection

Contrast detection thresholds did not differ between SCZ and NC ($t=0.78$, $df=83$, $P>0.05$). Contrast-detection thresholds were not significantly correlated with age in either SCZ ($r=0.10$, $P>0.05$) or NC ($r=0.15$, $P>0.05$). Contrast detection in SCZ was not significantly correlated with either duration of illness ($r=0.04$) or BPRS score ($r=0.00$). The type of antipsychotic drugs received appears to have an effect on contrast-detection thresholds in SCZ (Chen et al., 2003b). The thresholds of the patients who received typical agents (0.0066, $\sigma=0.007$, $n=10$) were significantly higher ($t=2.15$, $df=34$, $P=0.05$) than those of the patients who received atypical agents (0.0024, $\sigma=0.002$, $n=26$). The thresholds for those patients receiving both typical and atypical agents ($n=4$) and no antipsychotic medication ($n=4$) were 0.0025 ($\sigma=0.0002$) and 0.0014 ($\sigma=0.0004$), respectively. No significant gender differences were found in either NC ($t=-0.35$, $df=38$, $P=0.73$) or SCZ ($t=-0.59$, $df=42$, $P=0.55$) with respect to contrast detection.

4. Discussion

In the SCZ group, the thresholds for velocity discrimination were elevated above those of normal controls and the elevated thresholds appeared to be independent of age. Normal adults, on the other hand, showed significantly raised velocity-discrimination thresholds as early as after age 45. Both groups showed similar performance in contrast detection, and no age effects were observed.

Our result of a relatively stable velocity-discrimination deficit in SCZ independent of age contrasts with findings of age-related deterioration in specific neurophysiological deficits, such as backward visual masking (Green et al., 2003), eye tracking (Ross et al., 1999) and P300 event-related potentials (O'Donnell et al., 1995). A common finding in these studies is that aging degrades performance in normal adults and adds further impairment to existing deficits in patients. In the present study, the magnitude of the motion-discrimination deficit in SCZ did not worsen with age, suggesting that certain neural processes underlying aging and schizophrenia may not be independent, as would be the case if aging introduced an additional impairment to the motion deficit already present in schizophrenia.

Age-independent velocity discrimination in SCZ contrasts with age-dependent velocity discrimination in NC, whose performance decline starts as early as 45 years of age. It should be pointed out that significant age-related performance decline in NC was found only in the intermediate velocity condition (10°/s), where velocity cues are dominant. This velocity-selective age-related performance decline points to impairment in the mechanisms specific to velocity processing. No significant age effect at slow and fast velocities in the NC group suggests that the processing of non-motion information–position or contrast–is not affected at the early stage of aging. It should be noted that older NC subjects showed a trend towards impaired performance in the fast velocity condition (Table 2), a hint that the processing of temporally modulated visual information may also be vulnerable to aging by age 55 years.

One interpretation of this result could be that the pathophysiology of schizophrenia severely impairs motion discrimination and overshadows the age factor. Another possibility could be that the processes of aging and the possibility of psychopathological improvement during the later stages of schizophrenia (Bleuler, 1978; Ciompi, 1980; Harding et al., 1987; Mason et al., 1995) "neutralize" each other, producing effectively unchanged performance across this age span. The clinical measures used in this study (e.g. BPRS score and duration of illness), however, did not vary with velocity-discrimination performance in patients, which does not support this interpretation. As schizophrenia patients may not be a homogeneous group with respect to velocity-discrimination impairment, it is important to ask whether those patients who performed relatively well show an age effect in velocity discrimination that is similar to that of normal controls. The homogeneity analysis of the variance in the SCZ group across age does not support the notion that there were subgroups of patients whose VDTs were differentially affected by aging in any systematic way. Whether

this result can be generalized in a larger sample or to a larger age range remains to be seen.

Another interpretation of the differential age effects in SCZ and NC is that a common neural mechanism underlies the motion deficits in aging normal adults and in SCZ, but differs in timing. Hence, while normal aging impairs velocity discrimination, aging in SCZ does not worsen the velocity-discrimination deficit because the critical changes responsible for the impairment take place earlier in life and are not associated with a neurodegenerative process. We further discuss this interpretation below.

These findings are limited to patients and controls below age 55. The exclusion of much older subjects helped to minimize the effects of general functional decline in performance. This study cannot rule out the effects of medication because the group of unmedicated patients was small ($n=4$). Following patients longitudinally and extending the age range will be important for future research.

Although velocity discrimination in normal controls started to decline in the 40- to 50- year age range, contrast detection did not. The different effects of age on these processes are not surprising; velocity discrimination and contrast detection are mediated at different stages of the visual system (DeYoe and Van Essen, 1988). Owsley et al. (1983) reported that contrast sensitivity to moving gratings of low spatial frequency remains stable through early and middle adulthood, but it declines after age 60. In the present study, the NC and SCZ groups performed similarly in contrast detection, and performance was independent of age at least up to 55 years.

The velocity-discrimination results in normal adults indicate that this visual-capacity starts to decline around age 45. Velocity-discrimination thresholds at the intermediate base velocity (10°/s) increased in the 45- to 55-year subgroup by over 90%, compared with those of the three younger subgroups (18–44 years). Because velocity discrimination in the other velocity conditions (slow and fast) and contrast detection, which impose comparable cognitive demands, were stable in the age range tested, the selective age-related performance decline found when motion cues predominate cannot be attributed to a general decline of cognitive or visual systems at this early stage of the aging process. This interpretation is consistent with the finding that working memory systems are intact in normal adults through age 55 (Grady and Craik, 2000). Moreover, working memory deficits in SCZ do not impair performance on visual spatial tasks imposing a 500-ms delay (Park and Holzman, 1992). Therefore, declining or impaired working memory is not likely to account for the deficit in velocity discrimination in older normal adults or in schizophrenia patients in this study.

Our result showing similar motion-processing impairments after age 45 in normal adults and throughout adulthood in schizophrenia patients suggests that a common underlying neural factor may contribute to the occurrence of these deficits. Changes in GABAergic modulation have been shown in the aging visual cortical system (Spokes, 1979; Grachev and Apkarian, 2001; Leventhal et al., 2003), suggesting a possible candidate mechanism for the motion deficits that appear in the early stages of aging. The GABAergic system is also implicated in the pathophysiology of schizophrenia (see Benes, 2000, for a review). It is possible that GABAergic modulation of visual processing, already altered in schizophrenia by neurodevelopmental effects, is not further impaired by GABAergic changes that occur during aging as part of a neurodegenerative process. Hence, motion-processing systems are not affected twice by alteration of the same mechanism.

We suggest that a specific neural mechanism occurring relatively early in the aging process results in the decline of motion-discrimination capacities but does not impair other visual functions (such as contrast detection). Consistent with this suggestion are the results of Trick and Silverman (1991), which showed a distinct performance decline at the end of the fifth decade in the capacity to detect coherent motion (see the Table on p. 1438 of their article). As in Trick and Silverman (1991), the results of the present study support the idea that the processing of precise visual motion signals declines during the fifth decade. It has been shown recently that the aging of the human brain, as measured by reduced gene expression, begins during the fifth decade of life (Lu et al., 2004). Our finding suggests that motion discrimination may provide a sensitive indicator of early aging processes at the behavioral level.

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References

Ball, K., Sekuler, R., 1986. Improving visual perception in older observers. Journal of Gerontology 41, 176–182.

Benes, F.M., 2000. Emerging principles of altered neural circuitry in schizophrenia. Brain Research 31 (2–3), 251–269.

Bleuler, M.E., 1978. The long-term course of schizophrenic psychosis. In: Wynne, L.C., Cromwell, R.S., Matthysse, S. (Eds.), The Nature of Schizophrenia. Wiley, New York, pp. 631–636.

Chen, Y., Bedell, H.E., Frishman, L.J., Levi, D.M., 1998. Stimulus uncertainty affects velocity discrimination. Vision Research 38, 1265–1272.

Chen, Y., Levy, D.L., Nakayama, K., Matthysse, S., Palafox, G., Holzman, P.S., 1999a. Dependence of impaired eye tracking on deficient velocity discrimination in schizophrenia. Archives of General Psychiatry 56, 155–161.

Chen, Y., Nakayama, K., Levy, D.L., Matthysse, S., Holzman, P.S., 1999b. Psychophysical isolation of a motion-processing deficit in schizophrenics and their relatives and its association with impaired smooth pursuit. Proceedings of the National Academy of Sciences of the United States of America 96, 4724–4729.

Chen, Y., Palafox, G., Nakayama, K., Levy, D., Matthysse, S., Holzman, P., 1999c. Motion perception in schizophrenia. Archives of General Psychiatry 56, 149–154.

Chen, Y., Nakayama, K., Levy, D., Matthysse, S., Holzman, P., 2003a. Processing of global, but not local, motion direction is deficient in schizophrenia. Schizophrenia Research 61 (2–3), 215–227.

Chen, Y., Levy, D.L., Sheremata, S., Nakayama, K., Matthysse, S., Holzman, P.S., 2003b. Effects of typical, atypical, and no antipsychotic drugs on visual contrast detection in schizophrenia. American Journal of Psychiatry 160 (10), 1795–1801.

Ciompi, L., 1980. Catamnestic long-term study on the course of life and aging of schizophrenics. Schizophrenia Bulletin 6 (4), 606–618.

Cronin-Golomb, A., Corkin, S., Rizzo, J.F., Cohen, J., Growdon, J.H., Banks, K.S., 1991. Visual dysfunction in Alzheimer's disease: relation to normal aging. Annals of Neurology 29 (1), 41–52 (Erratum in: Annals of Neurology 29(3), 271, 1991).

DeYoe, E.A., Van Essen, D.C., 1988. Concurrent processing streams in monkey visual cortex. Trends of Neuroscience 11 (5), 219–226.

Friedman, L., Jesberger, J.A., Siever, L.J., Thompson, P., Mohs, R., Meltzer, H.Y., 1995. Smooth pursuit performance in patients with affective disorders or schizophrenia and normal controls: analysis with specific oculomotor measures, RMS error and qualitative ratings. Psychological Medicine 25, 387–403.

Gilmore, G.C., Wenk, H.E., Naylor, L.A., Stuve, T.A., 1992. Motion perception and aging. Psychology and Aging 7 (4), 654–660.

Grachev, I.D., Apkarian, A.V., 2001. Aging alters regional multichemical profile of the human brain: an in vivo ^{1}H-MRS study of young versus middle-aged subjects. Journal of Neurochemistry 76 (2), 582–593.

Grady, C.L., Craik, F.I., 2000. Changes in memory processing with age. Current Opinion in Neurobiology 10 (2), 224–231.

Green, M.F., Nuechterlein, K.H., Breitmeyer, B., Tsuang, J., Mintz, J., 2003. Forward and backward visual masking in schizophrenia: influence of age. Psychological Medicine 33 (5), 887–895.

Harding, C.M., Brooks, G.W., Ashikaga, T., Strauss, J.S., Breier, A., 1987. The Vermont longitudinal study of persons severe mental illness, II: long-term outcome of subjects who retrospectively met DSM-III criteria for schizophrenia. American Journal of Psychiatry 144 (6), 727–735 (June).

Hollingshead, A.B., 1965. Two Factor Index of Social Position. Privately Printed. Yale University, New Haven, CT 06520.

Holzman, P.S., Proctor, L.R., Hughes, D.W., 1973. Eye-tracking patterns in schizophrenia. Science 181, 179–181.

Holzman, P.S., Proctor, L.R., Levy, D.L., Yasillo, N.J., Meltzer, H.Y., Hurt, S.W., 1974. Eye tracking dysfunctions in schizophrenic patients and their relatives. Archives of General Psychiatry 31, 143–151.

Kendler, K.S., 1989. Structural Interview for Schizotypal Symptoms (SISS, version). Department of Psychiatry. Medical College of Virginia, Richmond, VA.

Leventhal, A.G., Wang, Y., Pu, M., Zhou, Y., Ma, Y., 2003. GABA and its agonists improved visual cortical function in senescent monkeys. Science 300 (5620), 812–815.

Levitt, D., 1972. The transformed up–down methods. Journal of the Acoustical Society of America 10, 465–479.

Levy, D.L., Holzman, P.S., Matthysse, S., Mendell, N.R., 1993. Eye tracking dysfunction and schizophrenia: a critical perspective. Schizophrenia Bulletin 19, 461–536.

Lu, T., Pan, Y., Kao, S.Y., Li, C., Kohane, I., Chan, J., Yankner, B.A., 2004. Gene regulation and DNA damage in the ageing human brain. Nature 429 (6994), 883–891.

McClelland, G.H., 2000. Nasty data: unruly, ill-mannered observations can ruin your analysis (Chapter 15). In: Reis, H.T., Judd, C.M. (Eds.), Handbook of Research Methods in Social and Personality Psychology. Cambridge University Press, Cambridge, UK, p. 393.

McKee, S.P., 1981. A local mechanism for differential velocity detection. Vision Research 21 (4), 491–500.

McKee, S.P., Silverman, G.H., Nakayama, K., 1986. Precise velocity discrimination despite random variations in temporal frequency and contrast. Vision Research 26 (4), 609–619.

Mason, P., Harrison, G., Glazebrook, C., Medley, I., Dalkin, T., Croudace, T., 1995. Characteristics of outcome in schizophrenia at 13 years. British Journal of Psychiatry 167 (5), 596–603.

Nakayama, K., Tyler, C.W., 1981. Psychophysical isolation of movement sensitivity by removal of familiar position cues. Vision Research 21 (4), 427–433.

Norman, J.F., Ross, H.E., Hawkes, L.M., Long, J.R., 2003. Aging and the perception of speed. Perception 32 (1), 85–96.

O'Donnell, B.F., Faux, S.F., McCarley, R.W., Kimble, M.O., Salisbury, D.F., Nestor, P.G., Kikinis, R., Jolesz, F.A., Shenton, M.E., 1995. Increased rate of P300 latency prolongation with age in schizophrenia. Electrophysiological evidence for a neurodegenerative process. Archives of General Psychiatry 52 (7), 544–549.

O'Donnell, B.F., Swearer, J.M., Smith, L.T., Nestor, P.G., Shenton, M.E., McCarley, R.W., 1996. Selective deficits in visual perception and recognition in schizophrenia. American Journal of Psychiatry 153 (5), 687–692.

Overall, J., Gorham, D., 1992. The Brief Psychiatric Rating Scale. Psychological Reports 10, 799–812.

Owsley, C., Sekuler, R., Siemsen, D., 1983. Contrast sensitivity throughout adulthood. Vision Research 23 (7), 689–699.

Park, S., Holzman, P.S., 1992. Schizophrenics show spatial working memory deficits. Archives of General Psychiatry 49 (12), 975–982.

Pasternak, T., 1987. Discrimination of differences in speed and flicker rate depends on directionally selective mechanisms. Vision Research 27 (11), 1881–1890.

Ross, R.G., Olincy, A., Harris, J.G., Radant, A., Adler, L.E., Compagnon, N., Freedman, R., 1999. The effects of age on a smooth pursuit tracking task in adults with schizophrenia and normal subjects. Biological Psychiatry 46 (3), 383–391.

Spitzer, R., William, J., Gibbon, M., First, M., 1994. Structured Clinical Interview for DSM-IV-Patient Edition (SCDI-P). American Psychiatric Press, Washington, DC.

Spokes, E.G., 1979. An analysis of factors influencing measurements of dopamine, noradrenaline, glutamate decarboxylase and choline acetylase in human post-mortem brain tissue. Brain 102 (2), 333–346.

Stuve, T.A., Friedman, L., Jesberger, J.A., Gilmore, G.C., Strauss, M.E., Meltzer, H.Y., 1997. The relationship between smooth pursuit performance, motion perception and sustained visual attention in patients with schizophrenia and normal controls. Psychological Medicine 27 (1), 143–152.

Sweeney, J.A., Haas, G.L., Li, S., 1992. Neuropsychological and eye movement abnormalities in first-episode and chronic schizophrenia. Schizophrenia Bulletin 18 (2), 283–293.

Trick, G.L., Silverman, S.E., 1991. Visual sensitivity to motion: age-related changes and deficits in senile dementia of the Alzheimer type. Neurology 41 (9), 1437–1440.

Wechsler, D., 1981. WAIS-R Manual. Psychological Corporation, New York.

Wertheim, A.H., van Gelder, P., Lautin, A., Peselow, E., Cohen, N., 1985. High thresholds for movement perception in schizophrenia may indicate abnormal extraneous noise levels of central vestibular activity. Biological Psychiatry 20 (11), 1197–1210.

Woods, S.W., 2003. Chlorpromazine equivalent doses for the newer atypical antipsychotics. Journal of Clinical Psychiatry 64, 663–667.