Intact perception of coherent motion, dynamic rigid form, and biological motion in chronic schizophrenia

Brian P. Keane[a,b,c,*,1], Yujia Peng[d,1], Docia Demmin[a], Steve M. Silverstein[a,b,c], Hongjing Lu[d,e]

[a] University Behavioral Health Care, Rutgers, The State University of New Jersey, United States
[b] Department of Psychiatry, Rutgers, Robert Wood Johnson Medical School, United States
[c] Center for Cognitive Science, Rutgers, The State University of New Jersey, United States
[d] Department of Psychology, University of California, Los Angeles, United States
[e] Department of Statistics, University of California, Los Angeles, United States

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ABSTRACT

Background: Prior studies have documented biological motion perception deficits in schizophrenia, but it remains unclear whether the impairments arise from poor social cognition, perceptual organization, basic motion processing, or sustained attention/motivation. To address the issue, we had 24 chronic schizophrenia patients and 27 healthy controls perform three tasks: coherent motion, where subjects indicated whether a cloud of dots drifted leftward or rightward; dynamic rigid form, where subjects determined the tilt direction of a translating, point-light rectangle; and biological motion, where subjects judged whether a human point-light figure walked leftward or rightward. Task difficulty was staircase controlled and depended on the directional variability of the background dot motion. Catch trials were added to verify task attentiveness and engagement.
Results: Patients and controls demonstrated similar performance thresholds and near-ceiling catch trial accuracy for each task (uncorrected $ps > 0.1$; $ds < 0.35$). In all but the coherent motion task, higher IQ correlated with better performance ($ps < 0.001$).
Conclusion: Schizophrenia patients have intact perception of motion coherence, dynamic rigid form, and biological motion at least for our sample and set-up. We speculate that previously documented biological motion perception deficits arose from task or stimulus differences or from group differences in IQ, attention, or motivation.

1. Introduction

Visual perception is altered in schizophrenia. One-quarter of patients endorse full-fledged visual hallucinations (Waters et al., 2014) and 60% report more subtle visual perceptual disturbances (Keane et al., 2018; Phillipson and Harris, 1985). Robust psychophysical deficits have been documented for visual processes ranging from low-level tasks such as contrast sensitivity (Slaghuis, 1998) and backward masking (Green et al., 2011) to middle-level tasks including contour integration and shape completion (Keane et al., 2014; Spencer et al., 2004), to high-level tasks such as affect recognition (Gaebel and Wölwer, 1992) and action recognition (Franck et al., 2001). Most relevant to the present discussion, people with schizophrenia are plausibly impaired at discriminating or detecting basic biological motion (Brittain et al., 2010; Kim et al., 2005,2011,2013; Kern et al., 2013; for a review, see Okruszek and Pilecka, 2017).

Biological motion perception entails combining spatiotemporal distal information to represent animate objects as fluid, dynamic, coherent, and meaningful. A prime example is the perception of vivid human actions from a few disconnected moving dots in a point-light display (Johansson, 1973). To achieve this percept, the visual system extracts the motion trajectories of each point to perceive human body structure (Lu, 2010), recognize action categories (van Boxtel and Lu, 2011), and infer social attributes such as affect (Pollick et al., 2001) and causal intention (Peng et al., 2017). Biological motion perception is implemented via specialized circuitry, including superior temporal sulcus and extrastriate body area (for reviews see Zilbovicius et al., 2006; Pavlova, 2011); it is phylogenetically primitive and ontogenetically early and may be disturbed in other disorders such as autism and Fragile X syndrome (Pavlova, 2011). A two-stage integration mechanism has been hypothesized to explain biological motion perception: the first stage analyzes the local motion signal and the second

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stage integrates the local motion signals to create spatial structure (Neri et al., 1998). Hence, biological motion perception constitutes one of the most sophisticated types of visual processing, with multiple levels of analysis for input information.

While poor biological motion perception in schizophrenia can be caused by any number of reasons, past clinical research suggests four candidate explanations. First, it is possible that people with schizophrenia are impaired at processing any type of motion (for a review, see Chen, 2011). Patients demonstrate poor speed discrimination (Clementz et al., 2007) and abnormal processing of center-surround suppression of motion, although the direction of the latter effect has not been consistent (Tadin et al., 2006; Chen et al., 2008). Second, biological motion perception deficits may result from poor perceptual organization (Silverstein and Keane, 2011). For example, people with schizophrenia have shown abnormal performance on tests of collinear facilitation (Must et al., 2004), contour integration (Silverstein et al., 2012,2000), and visual shape completion (Spencer et al., 2004; Keane et al., 2014). Third, the impairments may primarily derive from a lack of preference for socially relevant information (Kohler et al., 2009). This is considered reasonable because schizophrenia patients are impaired at processing socially relevant stimuli (Kelemen et al., 2005; Brittain et al., 2010), and because biological motion perception plays an important role in inferring social intention and interactions (Su et al., 2016). A final possibility that we will consider is that patients suffer from motivational/attentional deficits, which could generate categorically poor performance across behavioral tasks (for a review, see Fioravanti et al., 2012).

To examine the foregoing possibilities, we had healthy controls and schizophrenia patients engage in three tasks. In the coherent motion task, subjects indicated whether a cloud of dots drifted leftward or rightward; in the rigid form task, subjects indicated whether a randomly translating rectangle tilted left or right; in the biological motion task, subjects determined whether a walking figure faced left or right. Task difficulty depended on the directional variability of the background noise. A subset of the trials ("catch trials") was pitched at the easiest difficulty level so as to confirm that subjects understood and properly attended to each task. Tasks were designed to share most stimulus and procedural details so that they could be readily compared (see Methods).

Several patterns of results could emerge and each would yield insight. If patients perform equally poorly on all three tasks but normally on the catch trials, then that would suggest a generic motion perception deficit. If patients perform normally on the coherent motion task but poorly on the biological and rigid motion tasks, then that would suggest a deficit in dynamic perceptual organization. If patients exhibit greater impairments on biological motion than they do on the other tasks, then that may suggest a selective deficit for integrating socially relevant visual stimuli. Finally, if patients show similar performance as controls across these motion tasks, this result would suggest intact motion integration and perceptual organization in schizophrenia. There was no strong reason to prefer any one of these outcomes over another; any of the alternatives, if supported by the data, would shed light on the mechanisms underlying the putative deficit.

2. Methods

2.1. Participants

The study sample consisted of 24 patients with schizophrenia or schizoaffective disorder ($n = 1$) and 27 healthy controls (see Table 1). Inclusion criteria for controls were: (1) age between 18–65 years; (2) normal or corrected-to-normal visual acuity (see below), and (3) the ability to understand English and provide informed written consent. Inclusion criteria for patients were the same, but also included: (4) a DSM IV-TR diagnosis of schizophrenia or schizoaffective disorder (APA 2000). Exclusion criteria for patients were: (1) history of

traumatic brain injury or head injury with loss of consciousness greater than 10 min; (2) history of a neurological or developmental disorder; (3) a current mood disorder; (4) a substance use disorder in the last 6 months as assessed with the Mini International Neuropsychiatric Interview 6.0 (MINI; Sheehan et al., 1998) or positive urine toxicology screening on the day of testing; or (5) electroconvulsive therapy within the past 8 weeks. All patients were receiving antipsychotic medication. Exclusion criteria for the control group incorporated those for patients as well as: (1) any lifetime Axis-I mood or psychotic disorder (as assessed by SCID); (2) psychotropic medication use in the last 6 months; and (3) a first-degree relative(s) with a diagnosis of schizophrenia, schizoaffective disorder, or bipolar disorder (based on subject self-report).

An experienced clinician had established reliability with the consensus standards at the Rutgers Division of Schizophrenia Research (ICC > 0.8) and administered the clinical instruments and perceptual tasks. Psychiatric diagnosis was assessed with the Structured Clinical Interview for DSM-IV (SCID) (Spitzer et al., 2002) and was supplemented with electronic medical record information when the diagnosis was unclear. Intellectual functioning of all subjects was assessed with the Shipley-2 vocabulary subtest, which correlates highly with WAIS-III full-scale IQ ($r = 0.80$; Shipley et al., 2009, p. 65, Table 18). A vocabulary subtest was preferred since verbal knowledge may better reflect premorbid full-scale IQ in schizophrenia (Meier et al., 2014) and since vocabulary knowledge is one of the best predictors of full-scale IQ in healthy adults (Canivez and Watkins, 2010). Visual acuity was measured with a logarithmic visual acuity chart under fluorescent overhead lighting (viewing distance = 40 cm, lower limit = 20/10) and an in-house visual acuity correction kit was used for individuals without appropriate glasses or contacts. Each group had an average binocular acuity of 20/25 or better (logMAR < 0.1; see Table 1) and no subject had worse than 20/32 binocular acuity.

The Positive and Negative Syndrome Scale (PANSS; Kay et al., 1987), which was administered typically within 7 days of the perceptual task, provided information about symptoms over the last two weeks. PANSS symptom scores were reported via a "consensus" 5-factor model, which has been shown to be superior to the three-factor model (Wallwork et al., 2012). We tested for medication effects by first converting antipsychotic dosages to chlorpromazine equivalents based on published standards (Andreasen et al., 2010) and then correlating those values with task performance.

Written informed consent was obtained from all subjects after explanation of the nature and possible consequences of participation. The study followed the tenets of the Declaration of Helsinki and was approved by the Rutgers Institutional Review Board. All participants received monetary compensation and were naïve to the study's objectives.

2.2. Stimuli

All the stimuli were generated by MATLAB Psychtoolbox and were presented on a 22 in LCD monitor (viewable dimensions = 47.4 × 29.6 cm) with a resolution of 1680 × 1050 pixels and a 60 Hz refresh rate. Participants were seated 24 in (60.9 cm) from the screen. Stimuli in all the tasks were presented in a window that subtended 12° by 12° of visual angle, centered on the screen, and were displayed in black (0 cd/m^2) on a white background (145.5 cd/m^2).

2.2.1. CoherentMotion stimuli

A direction integration task was used in the present study (Williams and Sekuler, 1984). In each trial, 720 dots appeared with a random initial position and a density of 5 dots/deg^2 (see Fig. 1, top panel). The moving direction of each dot in the display was independently assigned by sampling from a uniform distribution that was centered on a reference direction and that had a certain range of motion directions. The reference direction was randomly selected, either left or right, on each trial. The direction range varied from 0° (i.e., all the dots

Table 1
Participant information.

Measure	Patients (N = 24)		Healthy controls (N = 27)		Test statistic	*P*-value
	Mean (SD)	Range	Mean (SD)	Range		
Age	39.33 (11.08)	[23, 58]	34.22 (12.33)	[18, 61]	t = 1.55	0.128
Gender ratio	23.5% female		76.5% female		$X^2 = 5.67$	0.017
Education in years	13.00 (2.02)	[10, 18]	14.33 (2.32)	[9, 18]	t = −2.18	0.034
Averaged parental education in years	11.88 (1.94)	[6.5, 16]	13.85 (3.01)	[6, 18.5]	t = −2.61	0.012
Visual acuity (LogMAR)	0.075 (0.07)	[0, 0.2]	0.007 (0.09)	[−0.2, 0.2]	U = 172.5	0.002
Shipley IQ score[a,b]	93.0 (16.0)	[56, 123]	102.7 (12.7)	[78, 121]	t = −2.39	0.021
PANSS total	70.42 (16.60)	[48, 106]				
PANSS positive	11.88 (5.14)	[4, 21]				
PANSS negative	12.63 (4.16)	[8, 24]				
PANSS disorganized	7.92 (2.83)	[3, 13]				
PANSS excited	9.83 (3.50)	[5, 17]				
PANSS depressed	8.54 (3.77)	[3, 15]				

[a] Missing data on one participant in the control group.

[b] One subject's IQ was 56. This person had low socio-economic status, a long psychiatric history, and history of stressful life events; cognitive impairments were also evident throughout the interview. To be inclusive, all patients were included in the study so long as they could perform the tasks as directed.

move to the immediate left or all move to the immediate right, yielding a strong perception of globally coherent motion) to 359° (i.e., dots move in random directions to show Brownian motion in which nearly no globally coherent motion can be perceived). Each dot was randomly assigned a speed between 1.5 and 4.5°/s, which is the same speed range as that used for the joints of the biological motion walker. Dots were given a limited lifetime in the range of 33.3–166.67 ms (2–10 frames), during which the speed and moving direction of a dot remained constant during its lifetime; dots were assigned a new speed and direction (but not location) when the lifetime expired. All dots were assigned a speed, direction, and lifetime independently and randomly from the same uniform distribution. Each trial lasted for 1.67 s. With a quasi-random assignment, half of the trials used the reference direction to the left, and the other half to the right. The target figures in the remaining two tasks were embedded in the same random dot display as that for CoherentMotion.

2.2.2. RigidForm stimuli

The target was a rectangle composed of 10 dots, which matched the number of point-lights used in the BioMotion task. As shown in Fig. 1 (middle panel), the ten dots were located at the corners, at the middle points of the shorter edges, and at the equally spaced positions along the longer edges. Even though dots were evenly distributed on each edge, the rectangle structure could not be perceived in a static frame. The size of the rectangle was 2° in width and 4° in height. The

rectangle's center always fell within a 2° × 2° spatial window centered on the screen, similar to the BioMotion figure. Throughout each trial, the rectangle tilted 45° to the left or right, which was assigned in a quasi-random manner. The starting position of the rectangle center was randomly chosen within the window. The rectangle's translational speed was always 2.86°/s, which corresponded to the average frame-to-frame speed of the 10 walker joints. The rectangle's moving direction was randomly assigned once at the beginning of a trial and once again whenever the center of the rectangle reached the spatial window boundary.

2.2.3. BioMotion stimuli

For the BioMotion task, a point-light walker (Johansson, 1973) was selected from the CMU motion-capture database (http://mocap.cs.cmu.edu) and processed by the BioMotion Toolbox (van Boxtel and Lu, 2013). The point-light walker consisted of 10 dots placed on the major joints, including head, elbows, hands, a hip joint, knees, and feet. The walker was presented in the profile view and moved in place without translating. The walker's size was a maximum of 2.5° in width and 5° in height; it's facing direction was quasi-randomly chosen to be left or right on each trial. The center of the walker was randomly positioned within a 2° × 2° spatial window that was centered on the screen.
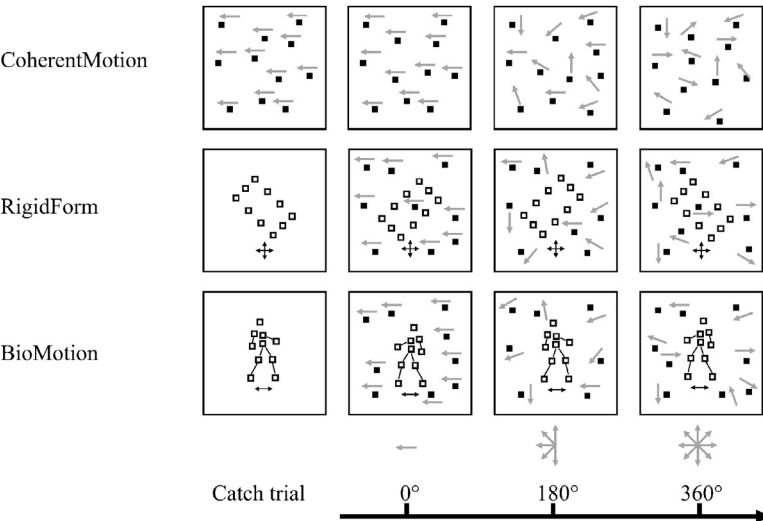
Fig. 1. *Sample static frames of the three motion tasks.* Each column refers to a given difficulty level. The gray arrows indicate the noise dot motion directions and were not presented during the experiment. The dots composing the rectangles and walkers are shown as hollow for illustration; in the actual experiment, they had the same size and color as the other dots. A video can be viewed in the supplementary materials.

2.3. Procedure

The procedure was nearly identical across tasks. Each began with 14 practice trials. In the first 5 practice trials, no noise dots were presented for the BioMotion and RigidForm tasks, and all the dots moved in the same direction for the CoherentMotion task. In the next 5 practice trials, the noise dots were always present and moved coherently with the direction range of 0°. In the last 4 trials, the noise dots moved in directions randomly sampled from the range of ± 180°.

After receiving practice, participants proceeded with a test block that consisted of 70 trials. Participants were asked to perform three blocks counterbalanced across participants; each consisting of a single task. The CoherentMotion task was to judge whether the global motion was leftward or rightward. The RigidForm task was to judge whether the rectangle tilt was to the left or right. The BioMotion task was to judge whether the point-light figure walked leftward or rightward. To avoid between-group differences in button press errors, we had subjects provide verbal rather than button press responses.

We used the Palamedes toolbox (Kingdom and Prins, 2016) to implement the Bayesian adaptive "Psi" staircase procedure, which simultaneously estimated the threshold and slope of the psychometric function after each trial (Kontsevich and Tyler, 1999). Threshold corresponded to the amount of directional variability needed to generate 80% accuracy in the discrimination tasks. The Psi method is advantageous in that it makes no assumption about slope—which can change from condition to condition—and provides arguably the most efficient method for simultaneously estimating the shape of two-parameter psychometric functions (Klein, 2001). Each staircase assumed a log-Weibull (Gumbel) function, a 0.5 guessing rate and a 0.02 lapse rate. The initial threshold values were estimated through a previous study with undergraduate students (van Boxtel et al., 2017). Two staircases, each with 30 trials, were quasi-randomly interleaved for each task. We averaged the two staircase thresholds to index task performance. Ten catch trials were randomly placed among the non-practice trials in each task. In the CoherentMotion task, the catch trials presented all the dots moving in the same direction (left or right); in the other two tasks, the catch trials presented the rigid form or point-light walker without the random dot background (see Fig. 1).

3. Results

The groups performed almost perfectly on the catch trials and uncorrected t-tests revealed no significant difference on any one task (all $ps > 0.1$; mean accuracy across tasks: schizophrenia = 98.33%, Control = 99.75%). Thresholds were next compared with a 2 (subject group) by 3 (task) mixed-design repeated-measures ANOVA. (There was a violation of the sphericity assumption (Mauchly's test, $\chi^2(2) = 6.3$, $p = 0.043$), and so we corrected the degrees of freedom using the Huynh–Feldt tests ($\varepsilon = 0.94$).) There was a significant main effect of task ($F_{1.88, 92.2} = 53.22$, $p < 0.001$, $\eta_p^2 = 0.521$). Follow up tests revealed lowest performance on the RigidForm, intermediate performance on the BioMotion, and best performance on the CoherentMotion (all $ps < 0.001$, after Bonferroni correction). Superior performance on the CoherentMotion relative to the BioMotion task replicated previous findings (Koldewyn et al., 2010; Spencer et al., 2013). To examine the impact of schizophrenia, we found that the main effect of group and interaction were not significant ($F_{1,49} = 0.41$, $p = 0.525$, $\eta_p^2 = 0.008$; $F_{1.88, 92.2} = 0.70$, $p = 0.491$, $\eta_p^2 = 0.014$). Specifically, there were no group differences for CoherentMotion ($t(49) = -0.348$, $p = 0.729$, $d = 0.098$), RigidForm ($t(49) = -1.24$, $p = 0.222$, $d = 0.341$), or BioMotion ($t(49) = 0.015$, $p = 0.988$, $d = 0.004$). The results remained the same after removing outliers (± 2 SD from the respective group means; see Fig. 2, indicated by circles).

To more directly assess the relative evidence for and against the

hypothesis of no group differences, we conducted a Bayes factor analysis with the default r-scale of Cauchy prior of 0.707 (which corresponds to an alternative hypothesis effect size of $d = 0.707$) (Rouder et al., 2009). The resulting Bayes factors were: RigidForm task 0.53 ± 0.02%, BioMotion 0.28 ± 0.02%, CoherentMotion 0.29 ± 0.02%, indicating the experimental results were at least two times more likely under the null hypothesis (no group difference in thresholds) than under the alternative hypothesis (a group difference in thresholds).

The patient and control groups differed demographically (see Table 1). To examine the relation between these and other variables on performance, we conducted a backward stepwise regression analysis for each task. The outcome variable was threshold, and the predictors were IQ, age, gender, education, visual acuity and subject group. The regression results confirmed the non-effect of group (all uncorrected $ps > 0.2$). For the CoherentMotion task, none of the predictors entered into the regression model were significant. However, for the RigidForm and BioMotion tasks, IQ was a significant predictor (RigidForm: $R^2 = 0.240$, $F(48) = 15.14$, $p < 0.001$; BioMotion: $R^2 = 0.172$, $F(1,48) = 9.94$, $p = 0.003$) (see Fig. 3). Follow-up moderation analyses revealed that subject group did not alter the IQ effects (BioMotion: $\Delta R^2 = 0.05$, $F(1,46) = 2.95$; $p = 0.09$; RigidForm: $\Delta R^2 < 0.01$, $F(1,46) = 0.03$; $p = 0.87$).

Gender composition differed significantly between groups (Table 1). To further confirm the non-significant effect of gender, we ran mixed-model ANOVAs with gender as the fixed factor and with thresholds as the dependent variables for three tasks; this was done for patients, for controls, and across patients and controls. This analysis revealed no effect of gender after FDR correction ($ps > 0.11$).

We next probed for inter-task relationships. Performance in the BioMotion task significantly correlated with performance in the RigidForm task for the control group ($r_\tau = 0.322$, $p = 0.018$) and patient group ($r_\tau = 0.312$, $p = 0.033$). Performance in the BioMotion task correlated with performance in the CoherentMotion task for controls ($r_\tau = 0.299$, $p = 0.029$) but not for patients ($r_\tau = -0.174$, $p = 0.234$). Performance in the RigidForm task correlated with performance in the CoherentMotion task for controls ($r_\tau = 0.305$, $p = 0.026$) but not for patients ($r_\tau = 0.196$, $p = 0.180$). When predicting biological motion thresholds, subject group did not significantly moderate the effect of RigidForm ($\Delta R^2 = 0.018$, $F(1,47) = 1.15$, $p = 0.289$) or CoherentMotion ($\Delta R^2 = 0.008$, $F(1,47) = 0.416$, $p = 0.52$). When predicting CoherentMotion thresholds, subject group did not significantly moderate the effect of RigidForm ($\Delta R^2 = 0.001$, $F(1,47) = 0.09$, $p = 0.766$).

4. Discussion

We investigated why schizophrenia has been associated with impairments in biological motion perception, and specifically, whether the impairment could be attributed to poor social cognition, perceptual organization, basic motion processing, or attention/motivation. To address these possibilities, we had schizophrenia patients and healthy controls discriminate the drift direction of global motion coherence (CoherentMotion), the tilt direction of bobbing point-light rectangles (RigidForm), or the walking direction of human point-light figures (BioMotion). Catch trials were added to ensure attentiveness and task comprehension. To our surprise, patients performed normally on the catch trials and tolerated as much directional noise as controls on each task, suggesting that motion integration may be generally intact in the disorder.

The discrepancy between our results and certain past studies requires an explanation. Two possibilities are worth ruling out right away. First, the null results cannot be attributed to our patients being especially asymptomatic or high functioning. Patients had lower IQ, lower education levels, and fewer years of parental education than controls (Table 1). Patients were moderately disabled with about 88
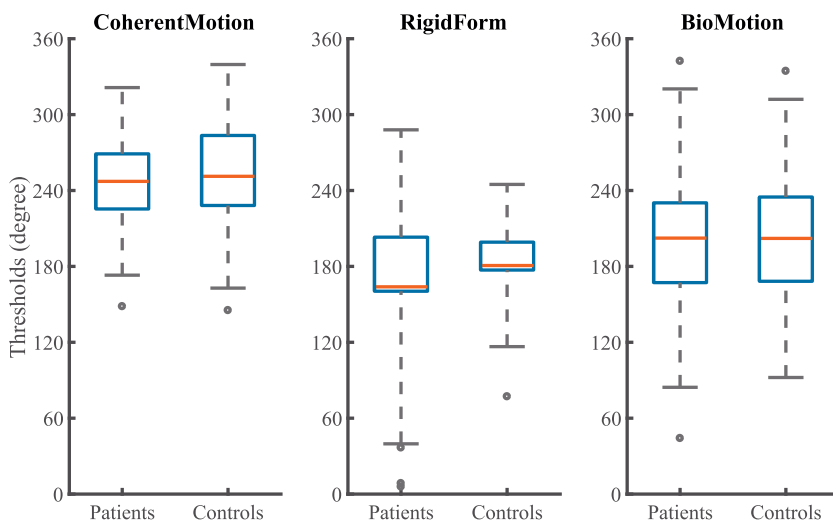
Fig. 2. *Threshold comparisons for each task.* Higher thresholds signify better performance—subjects can achieve threshold accuracy under noisier conditions (with more directional variability). On each plotted box, the central line indicates the mean, and the bottom and top edges indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers (± 2 SD).
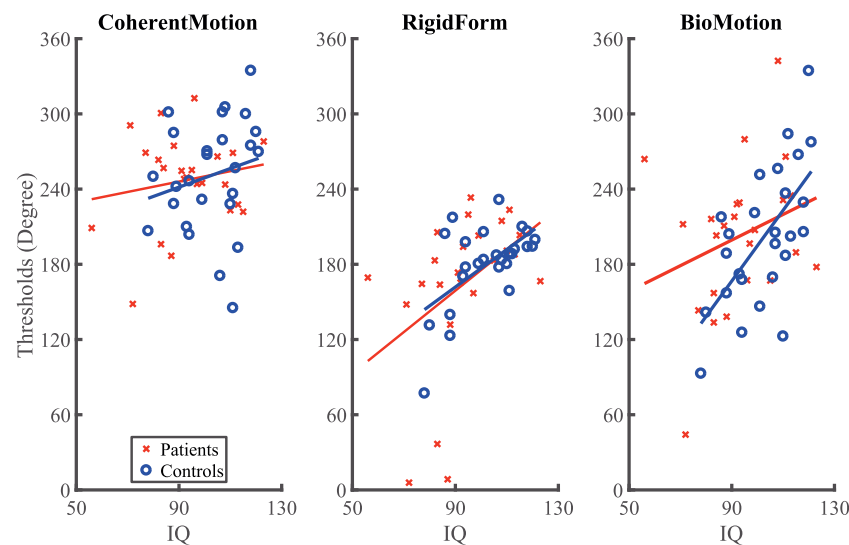

Fig. 3. *Scatterplots relating IQ to psychophysical thresholds.* Higher IQ significantly predicted better performance in the RigidForm and BioMotion tasks; subject group did not moderate these effects. Solid lines show the fitted regression lines.

percent receiving inpatient or partial hospital treatment; their mean PANSS scores also fell outside of the normal range for each symptom category (Positive, 3.0/item; Negative, 2.1/item; Disorganized, 2.6/item; Excited, 2.5/item; Depressed, 2.8/item).

Null results also cannot be attributed to noisy or inaccurate threshold measurements. We identified task-task and task-IQ correlations that were in the expected direction and that had at-times large magnitudes (see below). Performance was better in the CoherentMotion than the BioMotion task, which again replicates past findings (Koldewyn et al., 2010; Spencer et al., 2013) and is consistent with a "two-stage" model, where the visual system first detects local motion signals and then integrates those signals into a global figure or percept (Neri et al., 1998). The total number of trials (60/task) should also have been sufficient: in a previous contour integration study (Keane et al., 2016), patient contour integration deficits could be detected in each of the three 30-trial staircases ($ds > 0.95$; $ps < 0.001$). Moreover, our adaptive procedures worked as expected: all generated the expected mid-range accuracy, thus avoiding floor/ceiling effects (Mean (SD): Patient = 82% (6%); Control = 83% (4%).

One way to reconcile our results with those of years past is to appeal to the distinction between motion integration and motion segmentation (Figure 4). Previous reports of motion processing deficits in schizophrenia have been primarily based on performance in perceiving

unidirectional motion embedded in randomly moving noise dots (Bennett et al., 2016; Chen et al., 2005, 2003; Slaghuis et al., 2007). That task requires two independent processes: segregating coherent moving dots from noise dots, and integrating local signal motion information to form a global motion percept (Braddick, 1993; Newsome and Pare, 1988) (see Fig. 4). In contrast, the direction integration task used in the present study involves pooling motion signals across space but not segmenting coherently moving dots from a group of randomly moving (noise) dots. The two processes—motion segmentation and motion integration—may be supported by distinct neuron populations in MT (McDonald et al., 2014). Accordingly, Tibber et al. (2014) found that people with migraine performed worse relative to healthy controls in a motion coherence task (that requires motion segmentation), but similarly in a direction integration task. Similar results were obtained in children with autism (Manning et al., 2015).

It is possible that segmentation tasks elicit patient deficits primarily when the segmentation is more challenging (when the noise and signal dots move more similarly). Tibber et al. (2015) and Tso et al. (2014) reported normal patient performance on random dot kinematograms of coherent motion but the former study was pitched at an easier difficulty level (82% accuracy) and the latter involved noise dots with lower dot density (0.5 dots/deg^2) potentially making it easier for the signal dots to jump out. Our Biomotion and RigidForm tasks also contained subtle

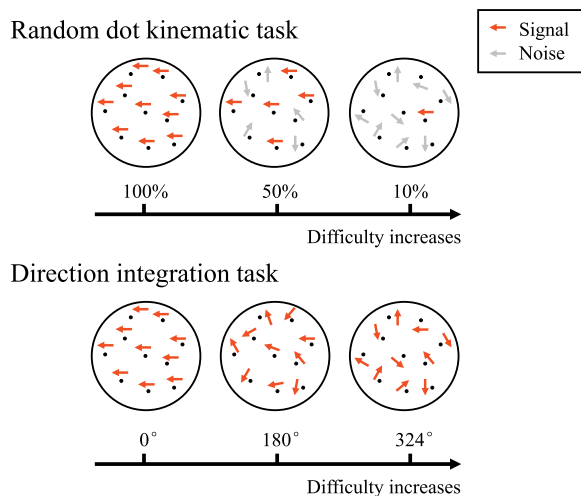Random dot kinematic task

Direction integration task

Fig. 4. *A comparison between two task types that are commonly used in testing coherent motion perception.* (Top) For random dot kinematic tasks, subjects must segment the signal dots from the randomly moving noise dots and the difficulty increases as fewer dots participate in lateral motion. (Bottom) For direction integration tasks, the difficulty increases as the dots' directional variability increases. In each task type, the darker red arrows denote signal and the lighter gray arrows, noise. Our results are compatible with the view that direction integration but not motion segmentation is intact in schizophrenia.

acceleration differences between the target and background, which may have differentially helped patients in segmenting signal dots. Salient segmentation cues could conceivably benefit patients more than controls and thus help explain the discrepancy with past studies that fully prevented such cues (e.g., Task 1 in Kim et al., 2013).

Other methodological differences may also be relevant. Slaghuis et al. (2007) found coherent motion deficits in schizophrenia patients for lower but not higher velocities. Chen et al. (2014) found speed discrimination deficits when the target had only low or moderate amounts of speed noise. Kim et al. (2005) suggest that patients may be more prone to falsely recognizing biological motion when discriminating intact and phase-scrambled point-like walkers (see also Task 3 of Kim et al., 2013). (Note that a phase-scrambled walker still appears as a human figure with distorted body movements and elicits a strong percept of animacy (Thurman and Lu, 2013,2014). Others have argued that more complex BioMotion recognition tasks may be needed to reveal underlying social cognitive deficits (Kim et al., 2013, p. 7).

Another possible reason for the discrepancy may be that our experimental design made generalized deficit confounds less likely. Our subjects provided verbal rather than button press responses, which obviated the need to memorize what key goes with what response and forced subjects to be continuously engaged with the experimenter from trial to trial. We also gave subjects ample practice—14 trials with a graduated level of difficulty. Catch trials additionally served to remind subjects of the true stimulus appearance, which could have been forgotten or misapprehended had only noisy exemplars been presented throughout. While it is beyond the scope of this article to give a full review of the weaknesses and strengths of all prior motion studies, small modifications to the procedure may very well spell the difference between finding or not finding a deficit, especially when the effect already lies near the boundary of non-significance (e.g., Brittain et al., 2010).

IQ differences may additionally help reconcile the findings. We found that IQ strongly correlated with performance on the RigidForm and BioMotion tasks. Higher IQ has been associated with superior biological motion perception in persons with autism (Koldewyn et al., 2010; Rutherford and Troje, 2012) and superior motion coherence in persons with schizophrenia (Tibber et al., 2015). This is important because, according to large-scale meta-analyses, people who go on to

develop schizophrenia score 0.43 standard deviations lower than the norm on IQ tests during the premorbid phase (∼93.5 on average; Khandaker et al., 2011) and so controlling for IQ should lessen group differences. Accordingly, Kim et al. (2013) found that—when verbal IQ was used as a covariate—group differences in coherent motion were no longer significant, group differences in D-prime (though not false alarms) in biological motion recognition were no longer significant, and group differences in biological motion discrimination remained significant, but became less so. In the present study, if we were to remove six high-scoring controls (IQs > 115) and thereby match groups on IQ ($p = 0.16$), patients would perform numerically (but not statistically) better on the better on the BioMotion and CoherentMotion tasks than controls. An IQ effect is potentially problematic because some schizophrenia studies report motion perception differences without further considering the role of IQ (Jahshan et al., 2014; Kern et al., 2013; Chen et al., 2003,2014). To be fair, an IQ confound does not by itself render perceptual differences uninteresting. Lower IQ is plausibly a core feature of schizophrenia (Kahn and Keefe, 2013) and poor motion perception may characterize the illness for this very reason. Moreover, as argued by others (Spencer et al., 2013), controlling for IQ is questionable at best and flawed at worst in that it removes variance associated with the illness itself (see also Miller and Chapman, 2001). Future studies will need to disentangle the inter-relation between IQ and perceptual performance in clinical and non-clinical populations.

To conclude, our study gives reason to revise the hypothesis that biological and non-biological motion perception is categorically impaired in schizophrenia. The group difference reported in past studies may be best attributed to lower patient IQ, reduced patient attention/motivation, motion segmentation, or other differences in experimental method. Of course, any result—null or otherwise—must be replicated to become established knowledge. We hope that others will extend our study to a wider range of stimulus variations while also carefully considering the potential confounds discussed above.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi: 10.1016/j.psychres.2018.06.052.

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