CONTEXTUAL MODULATION:

COMPONENTS OF THE ROD-AND-FRAME ILLUSION AND

THE SYSTEMIZING TRAIT OF AUTISM

by

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Individuals with autism tend to have superior sensory discrimination abilities and a locally-oriented cognitive style. The mechanisms that underlie these phenomena are unknown and may be linked to atypicalities in the contextual modulation occurring through mutually inhibitory interactions of neurons in early visual cortex. Prior work, in both monkeys and humans, has demonstrated that the perceived orientation of a line is distorted when presented in the context of other tilted lines (flankers), with the magnitude and direction of these effects dependent on the orientation and location of the flankers. With collateral flankers, the test line is perceived to be tilted away from flankers with 15 degree tilts, but this "perceptual repulsion" becomes smaller (or even a "perceptual attraction") with smaller flanker tilts. Experiment 1 examined the relationship between these contextual effects and the systemizing trait of autism. Individuals who scored high on the "insistence on sameness" subcomponent of systemizing were more sensitive in their orientation judgments, while showing a greater repulsive effect of the flankers. However, when the flankers were replaced with a small

tilted frame, the resulting repulsive effects (known as the Rod-and-Frame illusion) were even larger, but they were uncorrelated with insistence on sameness.

In Experiment 2, we dissected the frame into its component parts in an attempt to determine the specific features that drive the orientation contrast effects of the Rod-and-Frame illusion. We discovered that the left and right sides of the frame induced a significantly smaller repulsive effect than lateral flankers of the same tilt. However, the top and bottom of the frame induced a large repulsive effect that even exceeded that of the intact frame. These results indicate that the Rod-and-Frame illusion is the result of an underadditive combination of two independent contextual effects, though neither of these effects are correlated with insistence on sameness. Future work should further investigate this underadditivity, as well as the link between autism and local contrast effects. Such work may provide clues into how neural architecture differs in individuals with autism.

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Introduction

Autism: An Abridged History

In 1943, Dr. Leo Kanner published his clinical observations of 11 American children "whose condition differ[ed] so markedly and uniquely from anything [previously] reported," that it warranted detailed consideration by the mental health community. Though he acknowledged an array of individual differences within his sample, Kanner (1943) noticed that all 11 children shared a core set of traits. They had strong cognitive abilities. However, their intelligence was often overshadowed by a strong preference to be alone, deficits in social interaction, and language impairments. Kanner (1943) viewed these traits as a "disturbance of affective contact," or, in more simple terms, a lack of empathy. The children also had a strong insistence on sameness, which could manifest as repetitive or ritualistic behaviors. Indeed, Kanner's (1943) children with autism were often "governed by an anxiously obsessive desire for the maintenance of sameness that nobody but the child himself [could] disrupt on rare occasions. Changes of routine, of furniture arrangement, of a pattern, or the order in which every day acts [were] carried out [could] drive him to despair."

Although this syndrome was rare, it was affecting people worldwide. Hans Asperger (1944) published his description of four slightly older Austrian children who were intelligent, but had disturbances in their "physical appearances, expressive functions, and, indeed, their whole behavior." These characteristics resulted in a social phenotype similar to the one described by Kanner (1943). Interestingly, both physicians – working independently – used the same word to describe their patients. That word was autistic. The term was originally used to describe a particular schizophrenic behavior. More specifically, it referred to periods when a patient retreated into himself, withdrawing from the social world, and losing contact with reality. These linguistic roots reflect the consistent misdiagnosis of autism spectrum disorders (ASDs) that went on for decades.

During the mid-twentieth century, autism was considered an early presentation of childhood schizophrenia and thus had no consistent definition (Baker, 2013). The suspected cause was Freudian in nature. Practitioners believed that autism was the result of a cold parent-child relationship (later coined as the refrigerator mother theory; Kanner, 1949). It was not until the 1970s that the medical community defined autism as a biological disorder of brain development. Since then, the diagnostic criteria for autism (as listed in the *Diagnostic and Statistical Manual of Mental Disorders*, or DSM) have been slowly evolving. Changing definitions and increased awareness among clinicians have caused the rate of diagnosis to increase substantially in recent decades. Indeed, the Centers for Disease Control and Prevention (2014) now estimate that one in 68 American children have been diagnosed with an ASD. The condition is five times more common in boys than it is in girls.

Given its prevalence, autism is a serious public mental health concern. However, it still remains difficult to define. Establishing the cause of autism is difficult because the phenotype is highly heterogeneous. Individuals can be placed at different points along the spectrum based on their unique combinations of autistic traits. According to the DSM-5, autism is a pervasive neurodevelopmental disorder diagnostically characterized by deficits in social interaction and communication, repetitive behaviors, and restricted interests (American Psychiatric Association, 2013). These symptoms are usually apparent in the first two years of life.

Sensory and Perceptual Abnormalities in ASD

Sensory processing disorders are common in ASD. In comparison to age and gender-matched controls, the vast majority of people with autism experience abnormal auditory, visual, tactile, olfactory, kinesthetic, or proprioceptive processing at some point in their lives (Kern et al., 2006). These idiosyncrasies can include sensory distortions, sensory tune-outs, difficulties in cross-modal integration, and hypo- and hypersensitivity to stimulation (O'Neill & Jones, 1997). An unreliable perception of the world and sensory overload can cause distress in individuals with autism, resulting in defensive (stimulus avoidance) behaviors. By contrast, some individuals with autism are sensory seeking, becoming fixated on a particular stimulus in the environment. Both defensiveness and seeking behaviors may be observed within the same individual (Kern et al., 2006).

Those on the spectrum also perceive the world differently than neurotypical individuals. According to the Weak Central Coherence theory, they possess a locally oriented, highly analytical cognitive style (Happé & Frith, 2006). In the visual modality, when global properties of a scene are placed in competition with smaller details, individuals with autism are better attuned to the local features than neurotypical individuals. By analogy, instead of seeing the forest, people with autism often see the individual trees. In the laboratory, researchers have used a number of tasks and stimuli to demonstrate this local processing bias, including the hierarchical figures task, the block design task, the embedded figures task, and visuospatial illusions.

Demonstrations of a Local Processing Bias

The hierarchical figures task was pioneered by David Navon (1977). He presented participants with large (global) letters that were made up of smaller (local) letters. Depending on the trial type, participants were asked to identify either the global or local letter. Accuracy and response time served as the measures of performance. Navon (1977) found that the local letters had no effect on the recognition of the gestalt stimulus. That is, the smaller letters did not impede neurotypical participants from reporting the larger one in a timely manner. However, when participants were asked to identify the local letter, the global letter slowed response times, implying that the typically-developed visual system sees the “forest before the trees,” and thus has a global processing bias (Navon, 1977).

Plaisted, Swettenham and Rees (1999) looked for differences in performance on the hierarchical figures task between a group of children with autism and a neurotypical control group. They had two task conditions. In the divided attention task, participants had to indicate whether a target letter (which could be at either the local or global level) was present. In the selective attention task, subjects had to indicate what letter was presented within the target level. Plaisted et al. (1999) found that in the divided attention task, the typically-developing children were less accurate at the local level; by contrast, the group with autism was less accurate at the global level. Surprisingly, in the selective attention condition, both groups made more errors in the global level. That is, there was no significant difference in task performance between groups when participants were attending to a target level.

These data carry a few key implications. The group differences in the divided attention task imply that individuals with autism have a local processing bias. That is, by default, individuals with autism tend to look at the fine details of a visual scene while neglecting its gestalt properties. However, it is clear that this bias can be overridden. This can be seen in the lack of group differences in the selective attention task. It is not that individuals with autism possess a deficit in global processing or an enhancement of local processing, per se. Instead, it is the increased cost of an attentional switch from local to global aspects of a stimulus that creates a perceptual bias and cognitive style (Wang, Mottron, Peng, Berthiaume & Dawson, 2007; Happé, 1999).

A local processing bias can also be observed through use of the block design task (BDT). In these experimental protocols, researchers present participants with a set of blocks with colored patterns on each side. The participant's job is to rearrange these blocks to match a prescribed pattern. Performance is dictated by the speed and accuracy with which a subject forms the global pattern out of the local elements. Individuals with autism are superior at this task, both faster and more accurate than their typically-developing peers (Shah & Frith, 1993). Using functional imaging (fMRI), Bölte, Hubl, Holtmann and Poustka (2008) observed that, while performing the BDT, autistic individuals had less activation of the right ventral V2 than neurotypical controls. This region is involved in gestalt organization of shapes and patterns. Decreased activation in this region implies decreased global processing. Therefore, altered perception in the BDT could begin earlier than V2, through enhanced functioning in parvocellular pathways (Bölte et al., 2008).

In the embedded figures task (EFT), participants are presented with a complex figure and are asked to find a simpler shape embedded within it. In order to be successful at this task, the brain must suppress irrelevant contextual information and attend to the visual target. Individual differences exist in accuracy and search time because some people rely more heavily on contextual information than others and subsequently struggle to dissect the image into its parts. Similar to the block design task, individuals with autism often outperform their typically developing peers in this task. That is, they are faster and more accurate because they favor the local features over global properties of a stimulus (Shah & Frith, 1983).

Witkin and Goodenough (1981) found that performance on the embedded figures task was negatively correlated with susceptibility to some contextually-driven visual illusions. They attributed this relationship to differences in cognitive style. In neurotypical participants, Walter and Dassonville (2011) found that activation in a frontoparietal cortical network consistently underlies individual differences in EFT performance. They associated the process of suppressing irrelevant contextual information to disembed the visual target with increased activation of a neural network connecting the superior parietal cortex, precuneus, and middle frontal gyrus.

When autistic individuals perform the EFT, they show similar activation of visuospatial areas (bilateral superior parietal and right occipital cortices). However, they show less activation of the left frontal and inferior parietal regions, as well as less functional connectivity between higher-order working memory, executive function, and visuospatial regions (Damarla et al., 2010). This atypical neural processing of visual context could play a role in autistic perception.

The idea that autism is associated with atypical contextual processing, as specified in the Weak Central Coherence hypothesis, led to speculation that autism might be associated with a decreased susceptibility to visual illusions. With two-dimensional visual illusions, Happé (1996) found that individuals with autism were less susceptible, as they neglected global context in the stimuli. Furthermore, Bölte, Holtmann, Poustka, Scheurich and Schmidt (2007) found that autistic populations showed decreased hierarchical processing and immunity from the Titchener, Ponzo, Müller-Lyer, Poggendorf, and Hering illusions. These findings are in dispute, though, as Ropar and Mitchell (1999, 2001) have consistently found no relationship between Weak Central Coherence and illusory effects in ASD.

These competing results may be caused by the use of a clinical sample. Given the small sample size and heterogeneity of autistic symptoms, the use of a clinical sample can introduce error and produce mixed results. In order to overcome this potential source of sampling error, researchers can employ an individual differences approach. Autistic traits exist as a continuum within the neurotypical population (Grove, Baillie, Allison, Baron-Cohen & Hoekstra, 2013). By measuring the subclinical levels of certain autistic traits within the general population, researchers can better understand the link between illusion susceptibility, sensory sensitivity, and autism (Robertson & Simmons, 2012). Three self-report surveys have been developed to measure autistic tendencies in the neurotypical population. Those surveys are the autism quotient, the empathy quotient, and the systemizing quotient.

The autism quotient (AQ) measures the autistic tendencies of a typically-developed adult with normal intelligence (Baron-Cohen, Wheelwright, Skinner, Martin

& Clubley, 2001). In a sense, the AQ score provides a holistic view of a person's autistic tendencies. However, researchers are often interested in a specific autistic trait, such as decreased empathy. Those with autism often have a strong preference for being alone, and they frequently struggle with social interactions. They lack a theory of mind, making it difficult to understand the perspective of others (Baron-Cohen, Leslie & Frith, 1985). The empathy quotient (EQ) was designed to measure these autistic social tendencies within neurotypical adults of normal intelligence (Baron-Cohen & Wheelwright, 2004). Given their repetitive behaviors, restricted interests, and insistence on sameness, individuals with autism are also considered to be high systemizers. High systemizers view the world in a highly analytical way. They break systems down into component parts to better understand their mechanistic underpinnings. The systemizing quotient-revised (SQ-R) measures this trait in the general population (Wheelwright et al., 2006).

Walter, Dassonville and Bochsler (2009) used an individual differences approach to investigate the link between visuospatial illusion susceptibility and autistic tendencies with a neurotypical population. Along with a battery of perceptual tasks, they administered the AQ, EQ, and SQ to a neurotypical sample. They found that visuospatial illusion susceptibility was modulated by the systemizing trait of autism. Those who scored high in systemizing were less affected by the Rod-and-Frame, Roelofs, Ponzo, and Poggendorff illusions than their peers. The Zöllner and Ebbinghaus illusions loaded onto the same susceptibility factor but were not significantly correlated with systemizing. The Müller-Lyer and induced motion illusions loaded onto a different susceptibility factor that was not correlated with systemizing.

Reed and Dassonville (2012) tried to determine whether the relationship between systemizing and illusion susceptibility was caused by the diminished processing of global cues, the augmented processing of local cues, or some combination of the two. In order to make this determination, they focused on the Rod-and-Frame illusion. If a vertical line is surrounded by a tilted frame, it is typically perceived as being tilted in the opposite direction. Depending on frame size, the illusion is thought to be driven by a weighted average of two distinct mechanisms. In large frames, the observer's egocentric reference frame is distorted, biasing perceived vertical in the direction of the frame's tilt. This is a global, visuovestibular effect. In small frames, local orientation contrast effects early in visual processing are thought to drive the illusion. Reed and Dassonville (2012) found that high SQ-R scorers relied less heavily on global cues, and more heavily on local orientation cues. However, the global and local illusory effects were themselves uncorrelated. Instead, Reed and Dassonville (2012) discovered a two-factor structure to the SQ-R. Higher scores on the "analytical tendencies" factor predicted decreased global effects, while higher scores on the "insistence on sameness" factor predicted increased local orientation contrast effects. It is possible that these distinct perceptual mechanisms, while orthogonal in the general population, are comorbid in ASD.

Possible Neural Bases of a Local Processing Bias – Systems Level

The potential explanations for increased local contrast effects and a subsequent processing bias in autism are fiercely debated. In their Enhanced Perceptual Functioning model, Mottron, Dawon, Soulières, Hubert and Burack (2006) argue that individuals with autism have superior low-level sensory discrimination across multiple sensory modalities. In this model, the flow of sensory information through early neural pathways is enhanced, making it difficult – but not impossible – for attentional influences to control perceptual processes.

The specific neural substrates of Enhanced Perceptual Functioning and the local perceptual phenomenon are poorly understood. One theory posits that autism is associated with increased synaptic proliferation and decreased pruning, with the resulting atypical neural connectivity accounting for the autistic processing bias (White, O'Reilly & Frith, 2009; O'Reilly, Thiébaut & White, 2013). Hyde, Samson, Evans and Mottron (2010) used voxel-based morphometry and cortical thickness analyses to look for morphological differences in the brains of autistic and typically-developed adults matched in age, gender, IQ, and handedness. There were no significant differences in overall cortical thickness. However, in areas responsible for perception (such as primary visual and auditory cortices), the autistic brain was thicker and contained more gray matter. Higher cell density in these regions implies more local neural connectivity in addition to lower sensory thresholds. In comparison, the relative underconnectivity of frontal and posterior areas could lead to less global integration of visual information and could contribute to a local processing bias and other sensory processing disorders (Just, Cherkassky, Keller, Kana & Minshew, 2007).

Indeed, according to the Extreme Male Brain theory of autism, differences in neural organization may arise in utero (Baron-Cohen, Knickmeyer & Belmonte, 2005). Atypically high prenatal androgen exposure could lead to "hypermasculinization" of brain and behavior in both sexes. More specifically, in ASD, white-matter microarchitecture is skewed toward short-distance tracts instead of long-distance tracts

(Belmonte et al., 2004). The size of the corpus callosum is reduced, and the amygdala undergoes an atypical development that leads to a dampened activity (Amaral, Schumann & Nordahl, 2008; Baron-Cohen et al., 2000). These neuroanatomical differences could lead to decreased empathy and increased systemizing at all cognitive levels (Baron-Cohen, 2009). While some have suggested that this increased prenatal androgen exposure and supposed “hypermasculinization” might be an explanation for why a disproportionate number of males are affected by ASD, such claims are highly controversial and contested in the neuroscience and mental health communities (Krahn & Fenton, 2012; Bejerot et al., 2012).

In their Trigger-Threshold-Target model, Mottron, Belleville, Rouleau and Collignon (2014) suggest that people with autism also have low plasticity thresholds. Genetic mutations upregulate synaptic proliferation and reorganization of plastic cortical areas (like visual cortex). The target of cortical reorganization determines the unique phenotype of each person with autism. Assuming that plasticity thresholds are normal, a mutation that triggers perceptual reorganization creates Enhanced Perceptual Functioning at the cost of developing connections required for social skills and language.

An imbalance of excitatory and inhibitory neurotransmission within these abnormal pathways is another possible cause of Enhanced Perceptual Functioning in autism. Using magnetoencephalography (MEG), Velázquez and Galán (2013) investigated the differences in baseline neural activity between children with ASD and those who are developing neurotypically. They extracted the spontaneous activity from the MEG and determined that the autistic group had greater resting activity.

Hyperactivity of local neural microcircuits, primarily in the neocortex and amygdala, are the basis of the Intense World theory of autism. This theory suggests that hyper-reactivity and hyper-plasticity drive the hyper-attention, hyper-memory, hyper-emotionality, and hyper-perception that are characteristic of ASD (Markram & Markram, 2010). Increased levels of activation in key sensory regions (such as primary visual cortex) could lead to Enhanced Perceptual Functioning, a local processing bias, and symptoms characteristic of sensory processing disorders.

Possible Neural Bases of a Local Processing Bias – Cellular Level

All of the models cited previously look at potential differences in contextual processing at a systems level. That is, they focus on how abnormalities in the activity of neural networks could lead to a local processing bias and sensory processing disorders. However, it is potentially informative to consider how changes in contextual processing can occur at the cellular level as well. Neurons in primary visual cortex (V1) are tuned to bars of oriented light. A neuron's firing rate is maximal when a bar of light, oriented at the correct angle, enters its classical receptive field (Hubel & Wiesel, 1962). A neuron's tuning curve shows the firing rate of the cell as a function of line tilt and usually takes the form of a Gaussian distribution. The further away from the cell's preferred angle, the lower its firing rate. Preferred orientation columns are mapped topographically in primary visual cortex (Hubel & Wiesel, 1962).

Orientation columns in V1 are connected by inhibitory interneurons. When one cell is activated, it reduces the firing rate of its neighbor through lateral inhibition. In chemical synapses, the presynaptic interneurons release an inhibitory neurotransmitter (usually gamma-aminobutyric acid, GABA) across the synaptic cleft. When the neurotransmitter binds to its receptor on the post-synaptic cell, it causes a brief hyperpolarization (an inhibitory post-synaptic potential) and reduces the probability of an action potential. Through population coding, the brain can accurately determine the stimulus that is most likely present by averaging the differential firing rates of many neurons. However, under certain circumstances, these same mechanisms can trick the brain into misperceiving the orientation of a stimulus (Clifford, 2014). In so called tilt-illusions, the perceived orientation of a target stimulus is affected by the orientation structure of distractors in the visual field. For example, in the simultaneous tilt illusion, a vertical sinusoidal test grating can appear slanted in the presence of a rotated annulus grating. The magnitude and direction of the effect depends on the angle of the surrounding annulus grating (Figure 1).

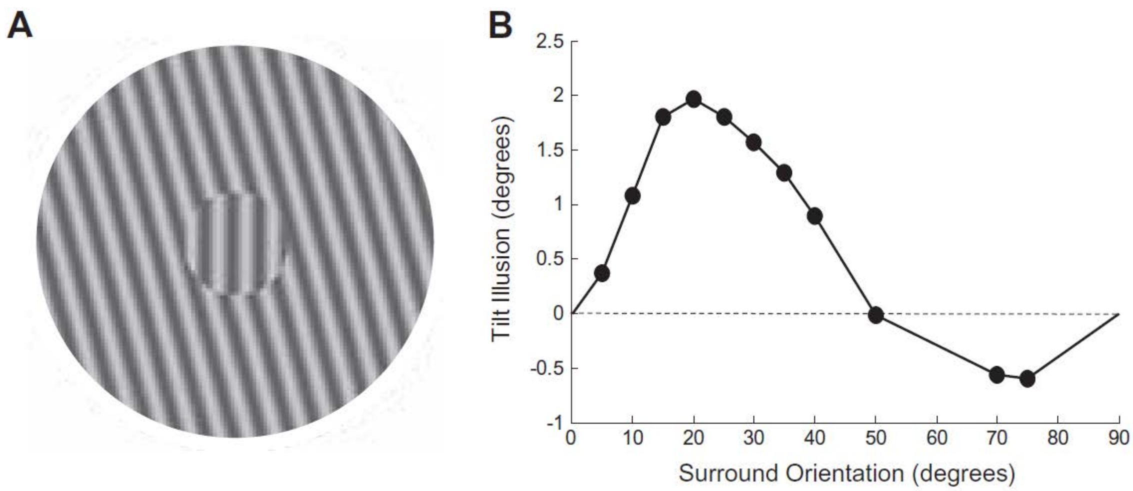

Figure 1: The Tilt-Illusion and its Angular Dependence (from Clifford, 2014)

(A) Example simultaneous-tilt stimulus. The vertical test grating in the center appears tilted in the opposite direction of the 15° surround grating. (B) Magnitude and direction of the tilt-illusion (with the test grating at vertical) as a function of the surround orientation (data from Westhemier, 1990). Unlike all other data presented in the current study, positive values indicate *repulsive* effects while negative values indicate *attractive* effects.

In a flanker task designed to examine such tilt-illusions at the level of single cells in V1, Kapadia, Westheimer and Gilbert (2000) presented monkeys and humans with an array of three lines: a center target surrounded by two flankers. Participants were asked to judge the perceived tilt of the center line in comparison to their perception of vertical. The flankers were in either the collinear (top-to-bottom) or collateral (side-to-side) axis relative to the target. All three lines were tilted slightly from vertical in varying directions and each was approximately the size of a single V1 receptive field; the contextual distractors (flankers) were positioned at the optimal distance from the target to encourage lateral inhibition and local orientation contrast effects.

Using this tilt-illusion paradigm, Kapadia et al. (2000) discovered that flankers in the collinear axis caused an attractive contextual effect. That is, when the flankers were in the collinear axis of the target, the perceived tilt of the center line was pulled in the direction of the flanker tilt. Contrastingly, when the flankers were in the collateral axis of the target, participants experienced a repulsive effect. That is, when the flankers were in the collateral axis, the target line was perceived to be tilted in the opposite direction (Figure 2).

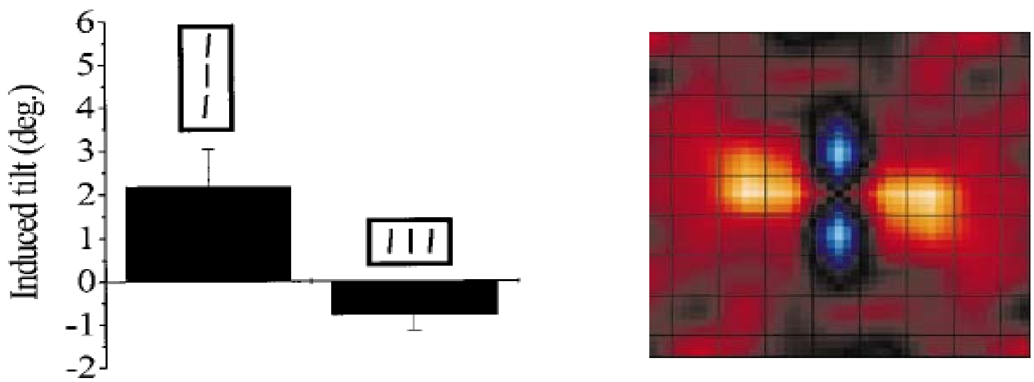

Figure 2: Flanker Effects (from Kapadia et al., 2000)

Left shows the induced tilt of the center target line in the presence of collinear and lateral flankers. Positive values indicate attractive effects, while negative values indicate repulsive effects. Heatmap at right shows that lateral inhibition (red) and collinear facilitation (blue) are neural substrates for such flanker effects. Inhibition was linked to repulsive flanker effects and facilitation was linked to attractive flanker effects.

To link these contextual effects to neurophysiology, Kapadia and colleagues (2000) mapped the receptive fields of individual neurons in primary visual cortex of the macaque using single-unit recordings. They found a spatial segregation of opposing contextual interactions within the receptive fields of individual neurons in primary visual cortex (Figure 2). Inhibitory contextual modulation of a neuron was strongest in the collateral axis, while excitatory contextual modulation was strongest along the collinear axis. Thus, they linked the attractive effect with increased excitation and the repulsive effect with increased inhibition.

Work in our lab has since replicated Kapadia and colleagues' psychophysical findings (Peterson, Kenny, Reed & Dassonville, 2015). We have found an attractive effect when flankers tilted by 15 degrees are placed along the collinear axis of the target stimulus, and repulsive effects when they are placed in collateral positions. Surprisingly, the collateral flankers could also cause a small attractive effect when they had only a slight (5 degree) deviation from vertical. Because we were interested in seeing how these contextual effects were modulated by autistic traits, we had our participants complete the AQ and the SQ-R.

It follows that, if individuals with autistic traits have more local connectivity between neurons in V1, there is an increased potential for inhibitory interactions to occur. This means that, though they would be more precise in their responses, individuals with autistic traits (i.e., an insistence on sameness) would experience greater local contrast effects in the flanker task (as Reed and Dassonville, 2012 found with the Rod-and-Frame illusion). As predicted, those who scored high on the insistence on sameness factor of the SQ-R experienced a greater net repulsive effect of the flankers and were more sensitive in their orientation judgments.

Present Study

In Experiment 1, we sought to replicate the findings of Peterson and colleagues (2015), but with more detailed variations in lateral flanker tilts. This allowed us to investigate the issues of attractive and repulsive effects more closely, and determine the flanker tilt where the contextual modulation in the collateral axis transitions from attractive to repulsive. We hypothesized that, because of greater net repulsion (caused by the cellular mechanisms described previously), contextual modulation would transition at less extreme tilts in those who scored high in the insistence on sameness factor of systemizing. We also predicted that they would be more precise in their responses.

Experiment 1

Methods

Participants

Participants were University of Oregon undergraduate students enrolled in a variety of psychology classes. They received course credit for their participation. All participants reported having normal or corrected-to-normal vision and no history of neurological deficits. In all, 139 people participated. However, for methodological reasons, 27 people had to be excluded from all analyses (see analysis section for further details). This left a sample of 112 participants (47 men, 65 women; M_{age} = 20.06 years, *SD* = 3.00). One-hundred-three were right-handed, six were left-handed, and two were ambidextrous. The handedness of one subject and the age of another were not reported. All participants gave informed consent in accordance with guidelines set by the University of Oregon Institutional Review Board, and they were debriefed at the end of the experiment.

Materials

Measures of Autistic Tendencies

Most participants completed the autism quotient (AQ; Baron-Cohen et al., 2001) and the systemizing quotient-revised (SQ-R; Wheelwright et al., 2006), two reliable self-report surveys that measure autistic tendencies within the neurotypical population. The AQ is made up of 50 questions, which can be divided into five categories: social skills, attention switching, attention to detail, communication, and imagination. Higher scores indicate greater autistic tendencies. While completing the AQ, participants indicated how much they agreed or disagreed with a statement on a four-point scale. Responses included “definitely agree,” “slightly agree,” “slightly disagree,” and “strongly disagree.” As per the scoring system used by Baron-Cohen and colleagues (2001) for the AQ, both of the “agree” responses (or both of the “disagree” responses for statements that were reverse-coded) received one point.

The SQ-R has 75 questions, with higher scores again indicating greater autistic tendencies. While completing the SQ-R, participants again specified how much they agreed or disagreed with a statement on a four-point scale. As with the AQ, the responses included “definitely agree,” “slightly agree,” “slightly disagree,” and “strongly disagree.” Unlike the AQ, for the SQ-R (Wheelwright et al., 2006), the “slightly agree” and “definitely agree” responses (or the “slightly disagree” and “definitely disagree” responses for statements that were reverse-coded) received one and two points, respectively. As discussed in the introduction, Reed and Dassonville (2012) found that, based on the content of the questions, a subset of the items in the SQ-R can be categorized into two distinct factors, with an “insistence on sameness” factor comprising 12 questions and an “analytical tendencies” factor comprising 26 questions (see the Appendix for survey items and further scoring specifics). Both surveys were completed in Qualtrics on a Macintosh computer (Apple Computers, Cupertino, CA). It took approximately 20 minutes total to complete both questionnaires.

Stimuli

There were three stimulus conditions (Figure 3). In the first, participants were presented with an array of three lines: a center target line surrounded by two lateral flankers. In the second, participants were presented with a center target line, which was encapsulated by a small tilted frame (because of an early programming error, the first five participants who completed the protocol did not receive this condition). In the third, participants were presented with only the center target line (i.e., there were no contextual distractors). For the flanker and no-context conditions, the target line was tilted -6, -4, -2, -1, 0, 1, 2, 4, or 6 degrees from vertical (positive values indicating rightward tilt). In the Rod-and-Frame condition, the center target line was tilted -10, -6, -4, -2, -1, 0, 1, 2, 4, 6, or 10 degrees from vertical. The flankers were tilted -15, -13, -11, -9, -7, -5, 5, 7, 9, 11, 13, or 15 degrees from vertical (both flankers having a tilt of the same direction and magnitude) and the frame was tilted -15 or 15 degrees from vertical. In each trial, the target and contextual conditions were independent of each other (e.g., target tilt = -6 degrees, flanker tilt = 9 degrees). The stimuli were composed of white lines presented on a black background (modeled after Kapadia et al., 2000). The target line and flankers were 12 minutes of visual angle in length and one minute of visual angle in width. In order to encapsulate the target line, the frame had to be larger, so each side measured 32 minutes

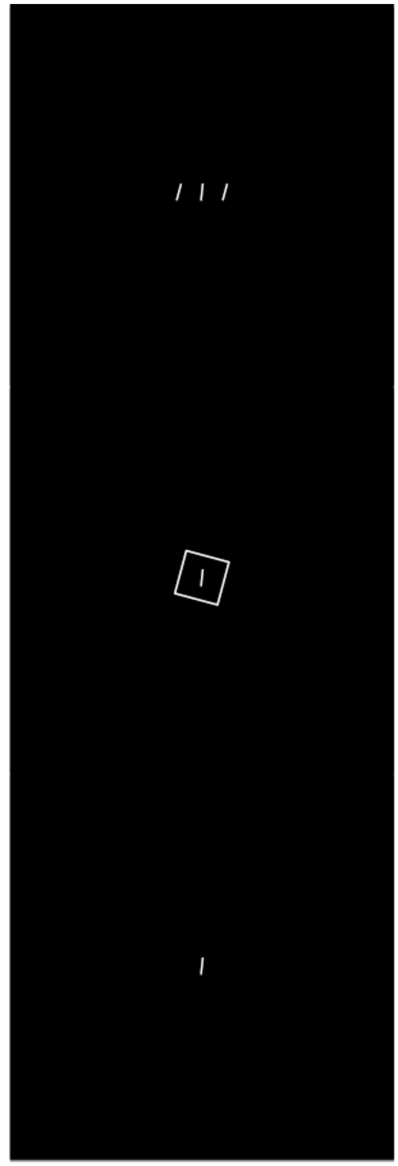

Figure 3: Stimuli – Experiment 1

Top panel gives sample flanker condition. Center panel gives sample Rod-and-Frame condition. Bottom panel gives sample no-context condition.

in length and one minute in width. The separation between the center target line and the contextual stimuli was 16 minutes, measured midpoint to midpoint.

Procedure

Each participant was seated comfortably in a dark room, with the head stabilized in a chinrest positioned 89 cm away from a Macintosh computer monitor (Apple Computers, Cupertino, CA). The screen measured 31 cm tall and 49.5 cm wide. Each trial began with a centralized fixation point. When participants were ready to begin a trial, they pressed the spacebar on the keyboard. A blank screen was presented for 200 ms, followed by the presentation of one of the context-target combinations for 100 ms (with the target line replacing the fixation point), and a blank screen until the participant's response. Regardless of the condition, the participant's task was exactly the same. That was, to judge the tilt of the center target line relative to perceived vertical. Leftward responses were indicated by pressing the "f" key on the keyboard and rightward responses were indicated by pressing the "j" key. In all, there were 139 different context-target combinations ((12 flanker conditions x 9 target conditions) + (1 no-context condition x 9 target conditions) + (2 frame conditions x 11 target conditions) = 139 context-target combinations). Each combination was presented randomly within eight experimental blocks (giving a total of 1112 experimental trials). A block of 16 random practice trials preceded the experimental trials. The flanker task took approximately one hour to complete. Participants also completed the AQ and SQ-R. The entire experimental protocol (which was counterbalanced across all participants) took approximately 90 minutes to complete.

Analysis

For each contextual condition, we used a psychometric function to calculate the point of subjective equality (PSE). The PSE is the orientation of the target line at which participants gave rightward and leftward responses with equal probability; that is, the orientation at which the target line appeared vertical to the participant. The form of the psychometric function was defined by the equation:

$$Proportion\ Rightward\ Responses = \frac{e^{\left(\frac{line\ tilt - PSE}{\tau}\right)}}{1 + e^{\left(\frac{line\ tilt - PSE}{\tau}\right)}}$$

In this equation, the line tilt was the orientation of the target line, PSE was the point of subjective equality, and tau was the space constant of the psychometric function. For each contextual condition, the PSE and tau were determined through an iterative adjustment to achieve the least-squared error between the psychometric function and the collected responses. The flanker effect was defined as the difference in PSEs for the positive and negative contextual conditions of a particular magnitude (e.g., the difference in the PSEs of -15 degree and +15 degree flanker tilts). Positive values indicated attractive tilt magnitudes and negative values indicated repulsive tilt magnitudes. The space constant, tau, served as a proxy for precision, with lower values indicating higher sensitivity.

We were unable to fit psychometric functions to the response data of 12 participants and 15 participants had poor task performance (precision), as indicated by the space constants of their psychometric functions ($Z \geq 3$). These 27 participants were excluded from all analyses. Because of time constraints, four of the remaining participants did not complete the AQ and three did not complete the SQ-R. These participants had to be excluded from analyses of individual differences.

Results

AQ and SQ-R

Descriptive statistics revealed that the mean AQ score was 15.80 (*SD* = 5.70), with a range of 6 to 32. The mean SQ-R score was 58.46 (*SD* = 19.72), with a range of 25 to 115. These mean values are well within the established norms for these surveys which are 16.4 (*SD* = 6.3) and 55.6 (*SD* = 19.7), respectively (Baron-Cohen et al., 2001; Wheelwright et al., 2006). This attests to the reliability of these two self-report measures and indicates that we did not have an atypical sample. See Table 1 for the descriptive statistics of the survey subscores.

	Mean	SD	Min.	Max.
***Autism Quotient (AQ)*:**				
Attention to Detail	5.55	2.02	1.00	10.00
Attention Switching	4.56	2.01	0.00	10.00
Communication	1.87	1.74	0.00	7.00
Imagination	1.99	1.59	0.00	7.00
Social Skills	1.83	2.05	0.00	8.00
***Systemizing Quotient-Revised (SQ-R)*:**				
Analytical Tendencies	19.50	9.60	2.00	46.00
Insistence on Sameness	11.20	5.08	1.00	23.00

Table 1: Descriptive Statistics for Survey Subscores – Experiment 1

Mean, standard deviation, minimum, and maximum values for the AQ and SQ-R subscores.

Flanker Task

Each of the contextual conditions created an illusory effect in the perceived tilt of the target line (Figure 4). One-sample t-tests revealed that all but one of these effects were statistically significant. The flankers induced a mean attractive effect if they were tilted five degrees (mean effect = 1.33 degrees, *SD* = 2.23, $t(111) = 6.28$, $p < .001$) or seven degrees from vertical (mean effect = 0.84 degrees, *SD* = 2.88, $t(111) = 3.10$, $p = .002$). The repulsive effect of the nine-degree flankers did not significantly differ from zero (*M* = 0.47 degrees, *SD* = 3.16, $t(111) = -1.57$, $p = .120$, ns). The flankers induced a mean repulsive effect with rotations of 11 degrees (mean effect = 1.52 degrees, *SD* = 3.48, $t(111) = -4.61$, $p < .001$), 13 degrees (mean effect = 2.64 degrees, *SD* = 4.22, $t(111) = -6.62$, $p < .001$), or 15 degrees from vertical (mean effect = 3.79 degrees, *SD* = 4.70, $t(111) = -8.53$, $p < .001$). The Rod-and-Frame condition induced a mean repulsive effect of 8.45 degrees (*SD* = 3.11, $t(106) = -28.05$, $p < .001$). These data indicate that, on average, the switch from attractive to repulsive occurs at flanker tilts of approximately nine degrees.

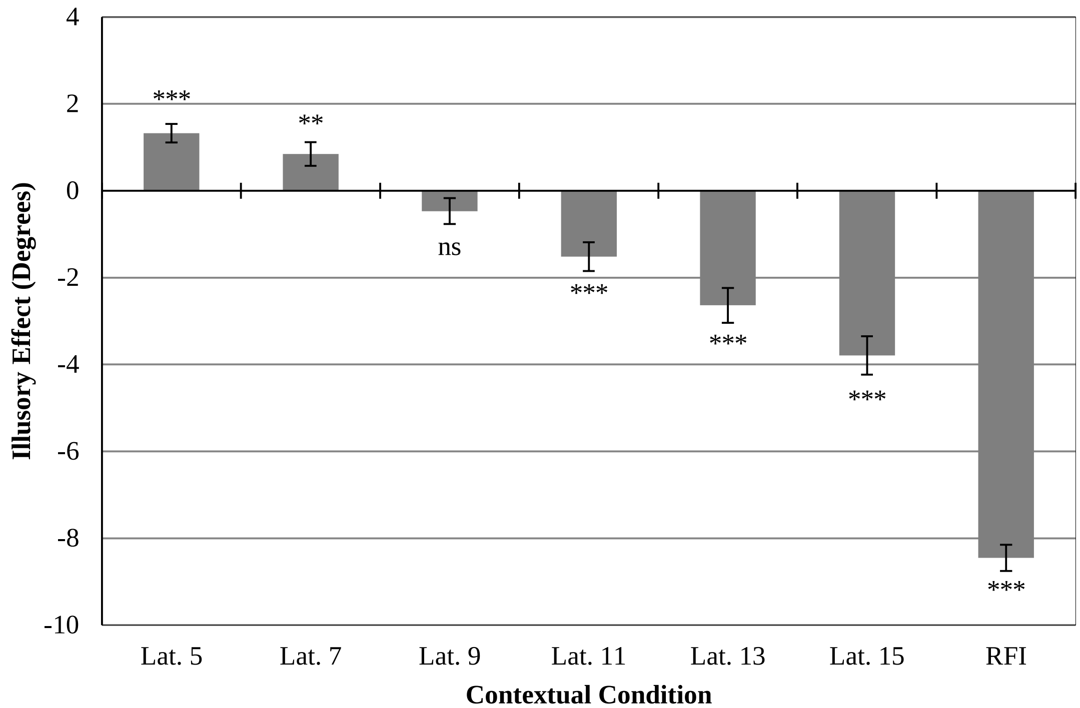

Figure 4: Illusory Effect of Contextual Conditions – Experiment 1

Comparison of the illusory effects for each contextual condition. Positive values indicate attractive effects, while negative values indicate repulsive effects. The average transition from attractive to repulsive occurs at flanker tilts of approximately nine degrees. Bars = mean ± SEM. For a one-sample t-test comparison value of zero, $p > .05$, ns, $^{**}p < .01$, $^{***}p < .001$. Flanker tilts of 5, 7, 9, 11, 13 and 15, n = 112; Rod-and-Frame, n = 107.

Relationship between Sensitivity and Insistence on Sameness

Prior to testing the relationship between sensitivity and the insistence on sameness (IS) component of the systemizing trait of autism, we employed an outlier detection technique. In computing the relationship between the IS score and sensitivity, ten participants were found to have studentized residuals with values greater than three. That is, given these participants' IS scores, the sensitivity in at least one contextual condition was highly abnormal. These outliers were excluded from this portion of the analysis.

A univariate general linear model showed a trending relationship between IS and the sensitivity of the orientation judgment when the target line was presented in isolation, $F(1, 97) = 3.19$, $p = .077$, ns. However, the relationship between IS and sensitivity may be non-linear. Because of that, we also performed a heteroscedastic independent-samples t-test to compare the mean sensitivity values in the no-context condition between the upper and lower quartiles of IS scores. This test revealed that, as predicted, higher IS scores were associated with heightened sensitivity, albeit in a non-linear way, $t(34.23) = 2.20$, $p = .034$.

To test this relationship across all contextual conditions, we performed a repeated-measures ANOVA using IS as a covariate, and sensitivity measures for all of the contextual conditions as a single within-subjects factor. This test demonstrated that a linear relationship was again trending, $F(1, 92) = 3.14$, $p = .08$, ns. To test the potential non-linear relationship, we also performed a repeated-measures ANOVA using the upper and lower quartiles of IS as a between-subjects factor. This test more conclusively confirmed that higher IS scores were associated with heightened sensitivity across conditions, though the relationship was likely non-linear, $F(1, 46) = 6.87$, $p = .012$ (Figure 5).

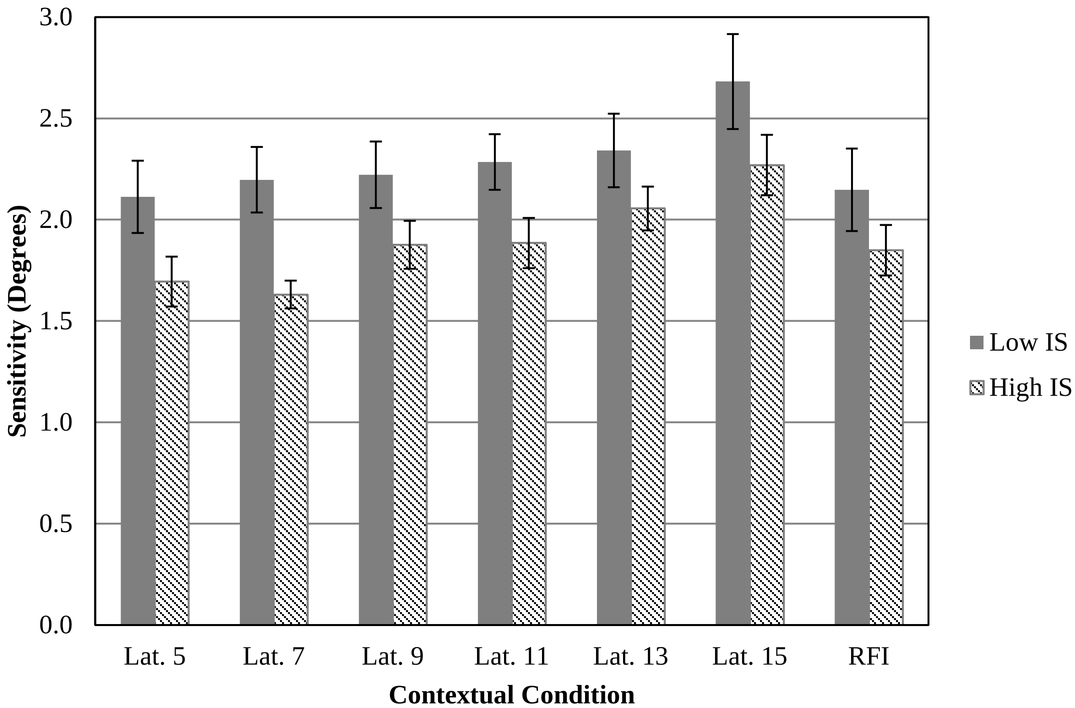

Figure 5: Quartile Split of Sensitivity – Experiment 1

Comparison of the sensitivity values for each contextual condition between upper and lower quartiles of IS. Lower values indicate greater sensitivity. High IS group shows greater sensitivity in all conditions. Bars = mean ± SEM. Flanker tilts of 5, 7, 9, 11, 13 and 15, low IS, n = 25, high IS, n = 27; Rod-and-Frame, low and high IS, n = 24.

Relationship between Contextual Effects and Insistence on Sameness

We also hypothesized that participants with high IS scores would experience greater net repulsion as a result of the flankers, causing them to switch from attractive to repulsive effects at a smaller flanker angle. Prior to testing this hypothesis, we employed the same outlier detection technique as described above and discovered that three participants had studentized residuals greater than three. Given their IS scores, the illusory effect of at least one flanker condition was highly abnormal. These outliers were excluded from this portion of the analysis.

A repeated-measures ANOVA using IS as a covariate and the illusory effects for each flanker condition as a single within-subjects factor revealed a significant linear relationship, $F(1, 104) = 4.98$, $p = .028$ (Figure 6). As predicted, higher IS scores were associated with more repulsive flanker effects, and, subsequently, a switch from attractive to repulsive at a smaller angle.

To test whether those with high IS scores experienced greater repulsion in all contextual conditions, we performed similar analyses with the Rod-and-Frame condition. Though the illusory effect of the Rod-and-Frame condition was positively correlated to each of the flanker effects, which were themselves correlated to IS (Table 2), it was not directly correlated with IS, $r(99) = -.001$, $p = .995$, ns. Indeed, an independent-samples t-test revealed no significant difference in the illusory effect of the Rod-and-Frame condition between the upper and lower quartiles of IS, $t(46) = 0.28$, $p = .780$, ns. These results imply that the repulsive flanker effects are correlated with IS, but that the repulsive effect of the frame is not (Figure 6).

		IS	5	7	9	11	13	15	RFI
IS	Pearson Correlation (*r*)	1	-.260**	-.278**	-.203*	-.199*	-.163	-.149	-.001
	Sig. (2-tailed)		.007	.004	.037	.041	.096	.128	.995
	N	106	106	106	106	106	106	106	101
5	Pearson Correlation (*r*)	-.260**	1	.784***	.744***	.704***	.668***	.626***	.271**
	Sig. (2-tailed)	.007		.000	.000	.000	.000	.000	.005
	N	106	109	109	109	109	109	109	104
7	Pearson Correlation (*r*)	-.278**	.784***	1	.831***	.808***	.791***	.753***	.347***
	Sig. (2-tailed)	.004	.000		.000	.000	.000	.000	.000
	N	106	109	109	109	109	109	109	104
9	Pearson Correlation (*r*)	-.203*	.744***	.831***	1	.877***	.868***	.840***	.382***
	Sig. (2-tailed)	.037	.000	.000		.000	.000	.000	.000
	N	106	109	109	109	109	109	109	104
11	Pearson Correlation (*r*)	-.199*	.704***	.808***	.877***	1	.903***	.848***	.365***
	Sig. (2-tailed)	.041	.000	.000	.000		.000	.000	.000
	N	106	109	109	109	109	109	109	104
13	Pearson Correlation (*r*)	-.163	.668***	.791***	.868***	.903***	1	.881***	.361***
	Sig. (2-tailed)	.096	.000	.000	.000	.000		.000	.000
	N	106	109	109	109	109	109	109	104
15	Pearson Correlation (*r*)	-.149	.626***	.753***	.840***	.848***	.881***	1	.372***
	Sig. (2-tailed)	.128	.000	.000	.000	.000	.000		.000
	N	106	109	109	109	109	109	109	104
RFI	Pearson Correlation (*r*)	-.001	.271**	.347***	.382***	.365***	.361***	.372***	1
	Sig. (2-tailed)	.995	.005	.000	.000	.000	.000	.000	
	N	101	104	104	104	104	104	104	104

Table 2: Correlations Between Contextual Effects and IS – Experiment 1

Pearson correlations for illusory contextual effects against IS and against each other. Though IS is correlated to most flanker conditions, and the flanker conditions are strongly correlated to the Rod-and-Frame condition, the Rod-and-Frame condition is not directly correlated to IS. **p* < .05, ***p* < .01, ****p* < .001.

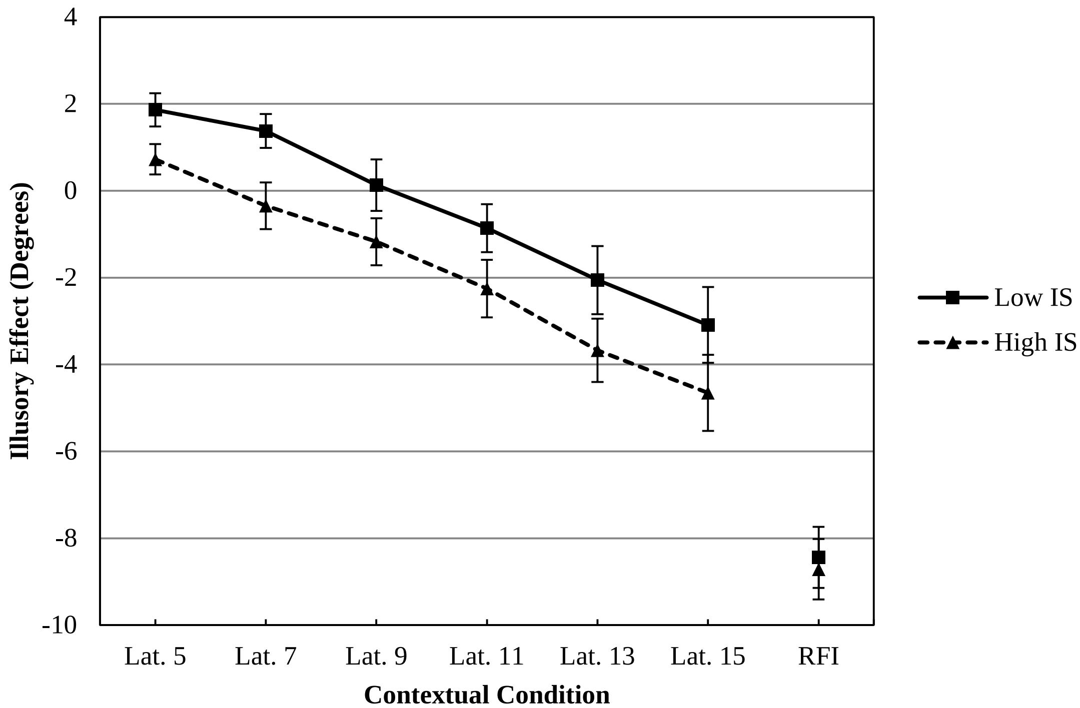

Figure 6: Quartile Split of Illusory Contextual Effects – Experiment 1

Comparison of the illusory effects for each contextual condition between the upper and lower quartiles of IS. Positive values indicate attractive effects, while negative values indicate repulsive effects. The transition from attractive to repulsive occurs at smaller flanker tilts in the high IS group. Points = mean ± SEM. Flanker tilts of 5, 7, 9, 11, 13, and 15, low IS, n = 25, high IS, n = 27; Rod-and-Frame, low and high IS, n = 24.

Discussion

In Experiment 1 we found that, on average, the transition from attractive to repulsive effects occurred at flanker tilts around nine degrees. Upon examination of the relationship between these contextual effects and the systemizing trait of autism, we found that individuals who scored high on the insistence on sameness component of systemizing were more sensitive in their orientation judgments, while also showing a greater repulsive effect of the flankers. This finding suggests greater local contrast effects within ASD. Greater net repulsion caused high IS scorers to transition from attractive to repulsive at smaller flanker tilts.

When the flankers were replaced with a small tilted frame, the repulsive effects were even larger, but they were uncorrelated with insistence on sameness. In Experiment 2, we dissected the frame into its component parts in an attempt to determine which specific features drove the repulsive effect while not being correlated to the systemizing trait of autism. We hypothesized that the contextual effect of the intact frame would be some weighted combination of the independent effects of the frame's left and right sides and its top and bottom. In addition, we expected to replicate the correlation between IS and the repulsive contextual effects of lateral flankers (specifically, the left and right sides of the frame in Experiment 2). We also anticipated the top and bottom of the frame to cause a substantial repulsive effect. However, given the assumption that the contextual effect of the intact frame (which did not correlate with IS) would be a weighted combination of the effect of the sides (which did correlate with IS) and that of the top and bottom, we predicted that the repulsive effect of the top and bottom would not correlate with IS. This null relationship could obscure the correlation of the contribution from the sides, making the intact frame effect unlinked to IS. Finally, we expected to replicate the relationship between IS and sensitivity observed in Experiment 1, with individuals scoring high on IS being more precise in their orientation judgments.

Autism and Obsessive Compulsive Disorder (OCD) share some common traits. More specifically, in comparison to controls, individuals with autism have been found to have higher frequencies of hoarding obsessions, and they are more likely to experience hoarding, repeating, and ordering compulsions (Ruta, Mugno, D'Arrigo, Vitiello & Mazzone, 2009). At the neuroanatomical level, ASD and OCD have both been linked to increased volume of the caudate nucleus of the basal ganglia. This increased volume leads to an atypically distributed neural network, which may underlie ritualistic-repetitive behaviors, unique motor mannerisms (tics), and an "insistence on sameness" (Sears et al., 1999). Additionally, like those with ASD, individuals with OCD have atypical global processing and struggle to process hierarchically presented stimuli (Rankins, Bradshaw & Georgiou-Karistianis, 2005).

Reed and Dassonville's (2012) "insistence on sameness" factor of the systemizing trait of autism is reminiscent of the symmetry, ordering, and arranging behaviors of OCD. Therefore, in Experiment 2, we included two reliable, self-report measures of subclinical OCD traits (Overduin & Furnham, 2012). These included the Symmetry, Ordering, and Arranging Questionnaire (SOAQ; Radomsky & Rachman, 2004) and the Vancouver Obsessional Compulsive Inventory (VOCI; Thordarson et al., 2004). From these two surveys, we were also able to derive scores on a third measure, the Vancouver Obsessional Compulsive Inventory-Revised (VOCI-R; Gönner et al., 2010). We were interested in exploring the relationship between autistic and obsessive-compulsive traits within a neurotypical sample. We also investigated the potential link between ASD, OCD, and differences in local perceptual processing.

By using the OCD measures to increase the number of items assessing tendencies associated with an insistence on sameness, we hoped to gain statistical power for our analyses of individual differences. Additionally, by using an adaptive stair-case design, we were able to shorten task duration. This likely improved task performance by preventing fatigue and attentional failure. By reducing noise and increasing statistical power, we predicted that Experiment 2 would give more robust and conclusive results than those found in Experiment 1, elucidating the link between ASD, OCD, and the orientation contrast effects of the Rod-and-Frame Illusion.

Experiment 2

Methods

Participants

Participants were students in the University of Oregon Human Subjects Pool. They received course credit or monetary compensation (at a rate of $10 per hour) in exchange for their participation. Prior to the experiment, all participants reported having normal or corrected-to-normal vision and no history of neurological deficits. In all, 106 people participated (34 men, 72 women; M_{age} = 20.39 years, *SD* = 2.27). Ninety-three were right-handed, eleven were left-handed, and two were ambidextrous. All participants gave informed consent in accordance with guidelines set by the University of Oregon Institutional Review Board and were offered a debriefing at the end of the experiment.

Materials

Measures of Autistic Tendencies

As in Experiment 1, participants completed the autism quotient (AQ; Baron-Cohen et al., 2001) and the systemizing quotient-revised (SQ-R; Wheelwright et al., 2006). See the materials section of Experiment 1 and the Appendix for administration procedures, survey items, and scoring specifics. As before, the two surveys were completed online through Qualtrics on a Macintosh computer (Apple Computers, Cupertino, CA) and took approximately 20 minutes total to complete.

Measures of Obsessive-Compulsive Tendencies

All participants completed the Vancouver Obsessional Compulsive Inventory (VOCI; Thordarson et al., 2004) and the Symmetry, Ordering, and Arranging Questionnaire (SOAQ; Radmosky & Rachman, 2004), two reliable self-report surveys that can measure obsessive-compulsive tendencies within a nonclinical sample. While completing the VOCI, participants indicated how accurately a statement described themselves on a five-point scale. Responses included "not at all," "a little," "some," "much," and "very much." As per the scoring system used by Thordarson and colleagues (2004), these responses received zero to four points, respectively. Higher scores indicated greater obsessive-compulsive tendencies. The VOCI has 55 questions, which can be divided into six categories: checking, contamination, hoarding, indecisiveness, just right, and obsessions.

While completing the SOAQ, participants again indicated how true each statement was of them on a five-point scale. As with the VOCI, responses on the SOAQ included "not at all," "a little," "some," "much," and "very much," and these responses received zero to four points, respectively. The SOAQ has twenty questions, with higher scores again indicating greater obsessive-compulsive tendencies. Both surveys were completed online through Qualtrics on a Macintosh computer (Apple Computers, Cupertino, CA) and took approximately 10 minutes total to complete.

From a subset of items on the VOCI and the SOAQ, we were able to derive scores on the Vancouver Obsessional Compulsive Inventory-Revised (VOCI-R; Gonner et al., 2010), which uses the same scoring system. We also calculated the five sub-scores of the VOCI-R: checking, contamination, hoarding, obsessions, and symmetry and ordering. The obsessions subscore is further divided into the harming and immoral categories. See the Appendix for survey items and further scoring specifics for all three measures of obsessive-compulsive tendencies.

Measure of Visual Acuity

Participants completed the Freiburg Visual Acuity Test (FrACT; Bach, 1996). In this automated measure of visual acuity, participants were presented with Landolt-Cs in one of four orientations, at a distance of two meters. They used the arrow keys on the keyboard to indicate the position of the gap in the stimulus. A best parameter estimation by sequential testing procedure was used to estimate the acuity threshold within a fixed number of trials (24). The FrACT was administered on a Macintosh computer (Apple Computers, Cupertino, CA). The screen measured 31 cm tall and 49.5 cm wide. The task took approximately two minutes to complete. The acuity of one participant was not measured.

Stimuli

There were three stimulus conditions (Figure 7). In the first condition, participants were presented with a center target line surrounded by a small tilted frame. In the second condition, participants were presented with an array of three lines: a center target and two flankers. The flankers were the components of the frame (i.e., the top and bottom in collinear locations or the left and right sides in lateral locations). In the third condition, participants were presented with only the target line (i.e, no context). Depending on the trial, the target had a tilt between -25 and 25 degrees from vertical; the frame and its components had tilts of either -15 or 15 degrees from vertical, with positive values indicating a rightward tilt. As in Experiment 1, the stimuli were composed of white lines presented on a black background. The target line was 12 minutes of visual angle in length and one minute of visual angle in width. The flankers (and subsequently the sides of the frame) were 32 minutes in length and one minute in width. The separation between the center target line and the contextual stimuli was 16 minutes, measured midpoint to midpoint.

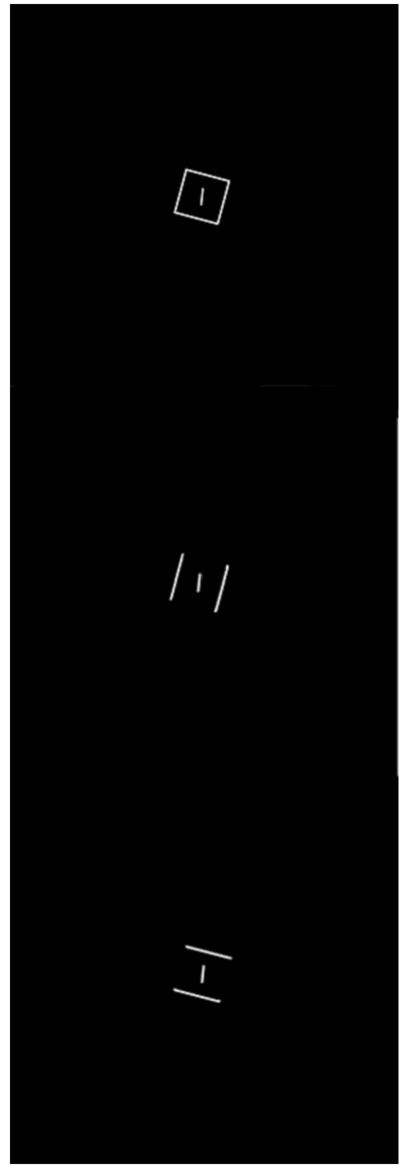

Figure 7: Stimuli – Experiment 2

Top panel gives sample intact frame condition. Center panel gives sample left/right condition. Bottom panel gives sample top/bottom condition. See Figure 3 (bottom panel) for no-context condition.

Procedure

Each participant was seated comfortably in a dark room, with the head stabilized in a chinrest positioned two meters from a Macintosh computer monitor (Apple Computers, Cupertino, CA). The screen measured 31 cm tall and 49.5 cm wide. Each trial began with fixation on a centralized vertical reference line. When participants were ready to begin a trial, they pressed the spacebar on the keyboard. The reference line remained on the screen for 500 ms. A blank screen was then shown for 500 ms, followed by the presentation of one of the context-target combinations for 200 ms (with the target line replacing the reference line), and a blank screen until the participant's response. Regardless of the condition, the participant's task was exactly the same; that was, to judge the tilt of the center target line relative to the vertical reference line. Leftward (counterclockwise) responses were indicated by pressing the “f” key on the keyboard and rightward (clockwise) responses were indicated by pressing the “j” key. Participants were required to take a one-minute break every 200 trials to maintain vigilance. The RFI component task took approximately 40 minutes to complete. Participants also completed the AQ, SQ-R, VOCI, SOAQ, and the FrACT, which were counterbalanced across all participants. The entire protocol took approximately 60 minutes to complete.

Analysis

For each contextual condition, we used an adaptive-step-size, one-up/one-down staircase procedure to determine the orientation of the target line that was reported as being rotated clockwise and counterclockwise with equal probability (points of subjective equality, or PSE; see García-Peréz, 1998 for a review). Each contextual condition had two staircases. The target line began with a tilt of -20 degrees (if approaching convergence from the left) or 20 degrees (if approaching convergence from the right). On each trial, the target’s tilt was adjusted in 16 degree increments away from the previous response until the first reversal (i.e., the first trial the participant gave the alternative response). The target’s tilt was then adjusted (in the opposite direction) in eight degree increments until the second reversal, and then by four degree increments until the third reversal. After the third reversal, the target’s tilt was adjusted in two degree increments until a total of 20 reversals had occurred. During each staircase, the target’s maximum deviation from vertical was capped at -25 or 25 degrees; these maxima rarely occurred, and only when participants inadvertently indicated the incorrect target line orientation early in the staircase, when the step size was large.

The mean target tilt of the final 14 reversals was used to determine where each staircase converged. The two staircases for each contextual condition were then averaged together to give the PSE. As in Experiment 1, the contextual effect was defined as the difference in PSEs for the positive and negative conditions of a particular stimulus type (e.g., the difference in the PSEs of the positively and negatively tilted left and right sides). Positive values again indicated attractive tilt magnitudes and negative values again indicated repulsive tilt magnitudes.

To calculate the sensitivity of orientation judgments, we used another set of adaptive-step-size, one-up/one-down staircases to find the target tilts – in the no-context condition – with 25% and 75% rightward response rates. Each response rate had two staircases. The target line began with a tilt of -20 degrees (if approaching convergence from the left) or 20 degrees (if approaching convergence from the right). For staircases converging toward the 25% rightward response rate, steps to the right were at 16 degree increments prior to the first reversal, eight degree increments prior to the second reversal, four degree increments prior to the third reversal, and two degree increments until a total of 20 reversals had occurred. Steps to the left were three times the size of steps to the right. That is, the target's tilt was adjusted in 48 degree increments prior to the first reversal, 24 degree increments prior to the second reversal, 12 degree increments prior to the third reversal, and six degree increments until a total of 20 reversals had occurred.

For staircases converging toward the 75% rightward response rate, the opposite was true. Steps to the left were at 16 degree increments prior to the first reversal, eight degree increments prior to the second reversal, four degree increments prior to the third reversal, and two degree increments until a total of 20 reversals had occurred. Steps to the right were three times the size of steps to the left. That is, the target's tilt was adjusted in 48 degree increments prior to the first reversal, 24 degree increments prior to the second reversal, 12 degree increments prior to the third reversal, and six degree increments until a total of 20 reversals had occurred. As before, the target's maximum deviation from vertical was capped at -25 or 25 degrees for all staircases used for measuring sensitivity.

The mean target tilt of the final 14 reversals was again used to determine where each staircase converged. The two staircases for each response rate were then averaged together to reduce potential bias. Sensitivity – the slope of the psychometric function of the form described in Experiment 1 – was defined as the difference between the 75% and 25% rightward response target tilts. Lower values indicated increased precision of orientation judgments.

Because of a computer hardware failure, we were unable to collect acuity or perceptual data from six participants. One participant had visual acuity worse than 20/40, and two participants had poor task performance, as indicated by abnormally high sensitivity values ($Z \geq 3$). These nine participants were excluded from all perceptual analyses.

Results

AQ, SQ-R, and VOCI-R

Descriptive statistics revealed that the mean AQ score was 16.84 (*SD* = 6.33), with a range of 3 to 41. The mean SQ-R score was 60.94 (*SD* = 17.31), with a range of 27 to 104. These mean values are well within the established norms for these surveys, which are 16.4 (*SD* = 6.3) and 55.6 (*SD* = 19.7), respectively (Baron-Cohen et al., 2001; Wheelwright et al., 2006). The mean VOCI-R score was 18.74 (*SD* = 16.24), with a range of 0 to 68. See Table 3 for the descriptive statistics of the survey subscores.

	Mean	SD	Min.	Max.
***Autism Quotient (AQ)*:**				
Attention to Detail	5.52	2.06	1.00	10.00
Attention Switching	5.08	2.11	1.00	10.00
Communication	2.05	1.87	0.00	9.00
Imagination	2.23	1.50	0.00	6.00
Social Skills	1.97	2.04	0.00	8.00
***Systemizing Quotient-Revised (SQ-R)*:**				
Analytical Tendencies	20.31	9.60	3.00	47.00
Insistence on Sameness	11.86	5.01	2.00	24.00
***Vancouver Obsessional Compulsive Inventory-Revised (VOCI-R)*:**				
Checking	3.73	5.18	0.00	24.00
Contamination	3.06	3.68	0.00	18.00
Hoarding	3.80	4.63	0.00	20.00
Obsessions	2.47	3.43	0.00	18.00
Harming Obsessions	1.38	2.25	0.00	12.00
Immoral Obsessions	1.09	1.78	0.00	9.00
Symmetry and Ordering	5.68	5.45	0.00	22.00

Table 3: Descriptive Statistics for Survey Subscores – Experiment 2

Mean, standard deviation, minimum and maximum values for the AQ, SQ-R, and VOCI-R subscores.

We also obtained general measures of shared traits between ASD and OCD. To do this, we performed a varimax-rotated principle components analysis using the subscores of AQ, SQ-R, and VOCI-R as its input. This analysis exposed four factors that accounted for 63.44% of the total variance in the scores of the three surveys (Table 4). The first of these factors (termed here as the *obsessive-compulsive tendencies* factor, based on the components that form it) was driven by the checking, contamination, hoarding, and symmetry and ordering subscores of the VOCI-R, accounting for 32.60% of the variance. It should be noted that for the obsessive-compulsive factor, the obsessions subscore of the VOCI-R, with a loading weight of 0.399, was just below the threshold of ±0.4. The second of these factors (the *autistic tendencies* factor) was driven by the attention switching, communication, imagination, and social subscores of the AQ and the obsessions subscore of the VOCI-R, accounting for 12.11% of the variance.

The third of these factors (the *insistence on sameness/symmetry & ordering* factor) was driven by the attention to detail and attention switching subscores of the AQ, the insistence on sameness factor of the SQ-R, and the symmetry and ordering subscore of the VOCI-R, accounting for 9.65% of the variance. The final factor (the *analytical tendencies* factor) was driven by the attention to detail subscore of the AQ and the analytical tendencies subscore of the SQ-R, accounting for 9.08% of the variance.

	Factor 1	Factor 2	Factor 3	Factor 4
***AQ*:**				
Attention to Detail	0.122	-0.007	**0.441**	**0.491**
Attention Switching	0.369	**0.502**	**0.527**	-0.009
Communication	0.228	**0.759**	-0.049	-0.002
Imagination	0.033	**0.644**	0.051	0.368
Social Skills	0.069	**0.788**	0.175	0.101
***SQ-R*:**				
Analytical Tendencies	0.005	0.171	-0.158	**0.780**
Insistence on Sameness	0.034	0.060	**0.889**	-0.069
***VOCI-R*:**				
Checking	**0.645**	0.089	0.138	0.347
Contamination	**0.802**	0.049	0.105	0.065
Hoarding	**0.775**	0.283	-0.037	-0.130
Obsessions	0.399	**0.481**	0.125	-0.311
Symmetry and Ordering	**0.639**	0.202	**0.551**	-0.068

Table 4: Varimax-rotated Component Matrix for Questionnaires – Experiment 2

Results of the factor analysis for AQ, SQ-R and VOCI-R subscores. Values highlighted in **bold** had loading weights that surpassed a threshold of ±0.4.

RFI Component Task

Each of the contextual conditions created an illusory effect in the perceived tilt of the target line (Figure 8). One-sample t-tests revealed that all of these effects were statistically significant. The left and right sides of the frame induced a mean repulsive effect of 1.44 degrees (SD = 3.67, t(96) = 3.87, p < .001), and the top and bottom of the frame induced a mean repulsive effect of 7.60 degrees (SD = 3.00, t(96) = 24.97, p < .001). The intact frame elicited a mean repulsive effect of 6.78 degrees (SD = 3.00, t(96) = 22.27, p < .001).

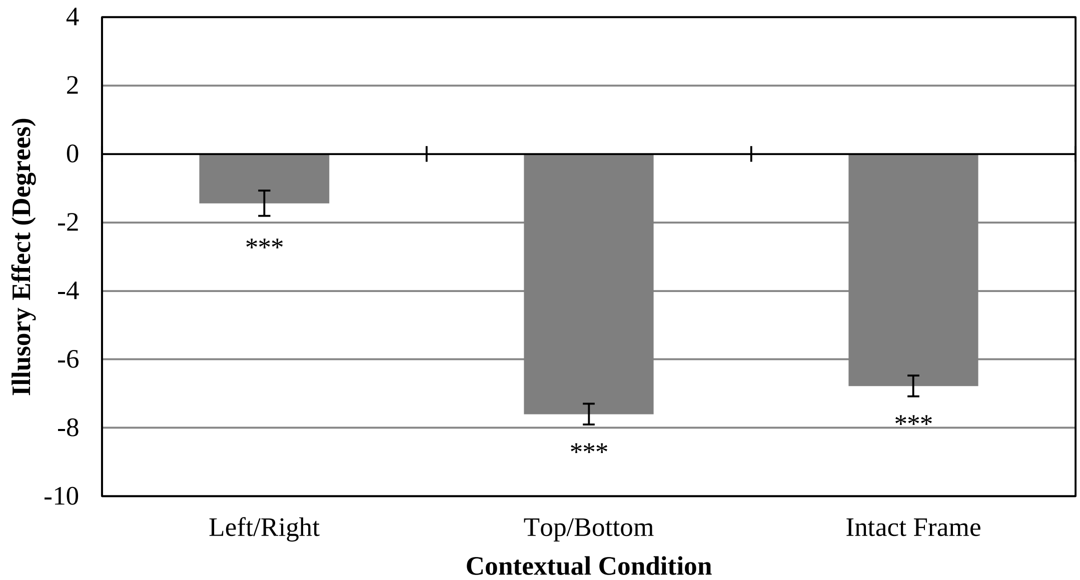

Figure 8: Illusory Effect of Contextual Conditions – Experiment 2

Comparison of the illusory effects for each contextual condition. Positive values indicate attractive effects, while negative values indicate repulsive effects. Bars = mean ± SEM. For a one-sample t-test comparison value of zero, ***$p < .001$. All pairwise comparisons between conditions were statistically significant.

A repeated-measures ANOVA with a Greenhouse-Geisser correction determined that the illusory effects were significantly different between contextual conditions, $F(1.52, 96) = 171.77$, $p < .001$. More specifically, Bonferroni-corrected post hoc analyses showed that the effect of the left and right sides of the frame was significantly smaller than the effects of the top and bottom of the frame (mean difference = -6.16 degrees, $p < .001$) and the intact frame (mean difference = -5.34 degrees, $p < .001$). Perhaps most importantly, the effect of the top and bottom of the frame even surpassed that of the intact frame (mean difference = 0.82 degrees, $p = .025$). Thus, the effect of the intact frame was less than the sum of its parts.

The effect of the intact frame was positively correlated with the effects of the top and bottom ($r(95) = .50$, $p < .001$; Figure 9A) and the left and right sides ($r(95) =$

.61, $p < .001$; Figure 9B). However, the effects of the two component conditions were not correlated to each other ($r(95) = .12$, $p = .231$, ns; Figure 9C). Therefore, our results indicate that the overall effect of the frame was a weighted average of the two flanker conditions. This suggests an underadditivity of the orthogonal mechanisms responsible for the orientation contrast effects of lateral and collinear flankers.

More specifically, a multiple regression revealed that the effects of both component conditions predicted the effect of the intact frame, $F(2, 94) = 56.92$, $p < .001$. In this model, for every additional degree of the side flanker effect, the intact frame effect increased by 0.45 degrees. Likewise, for every additional degree of the top and bottom flanker effect, the intact frame effect increased by 0.43 degrees. The regression had a significant intercept, such that a theoretical participant with no effect in the two component conditions was predicted to have an intact frame effect of 2.87 degrees.

In light of the fact that the intact frame effect was actually *less* than the sum of its parts, we ran a second model, which suppressed the intercept (i.e., forced the regression line through the origin). In this second model, both component conditions were still predictors of the intact frame effect, albeit with different parameter estimates $F(2, 95) = 461.25$, $p < .001$. For every additional degree of the side flanker effect, the intact frame effect increased by 0.46 degrees; and for every additional degree of the top and bottom effect, the intact frame increased by 0.75 degrees.

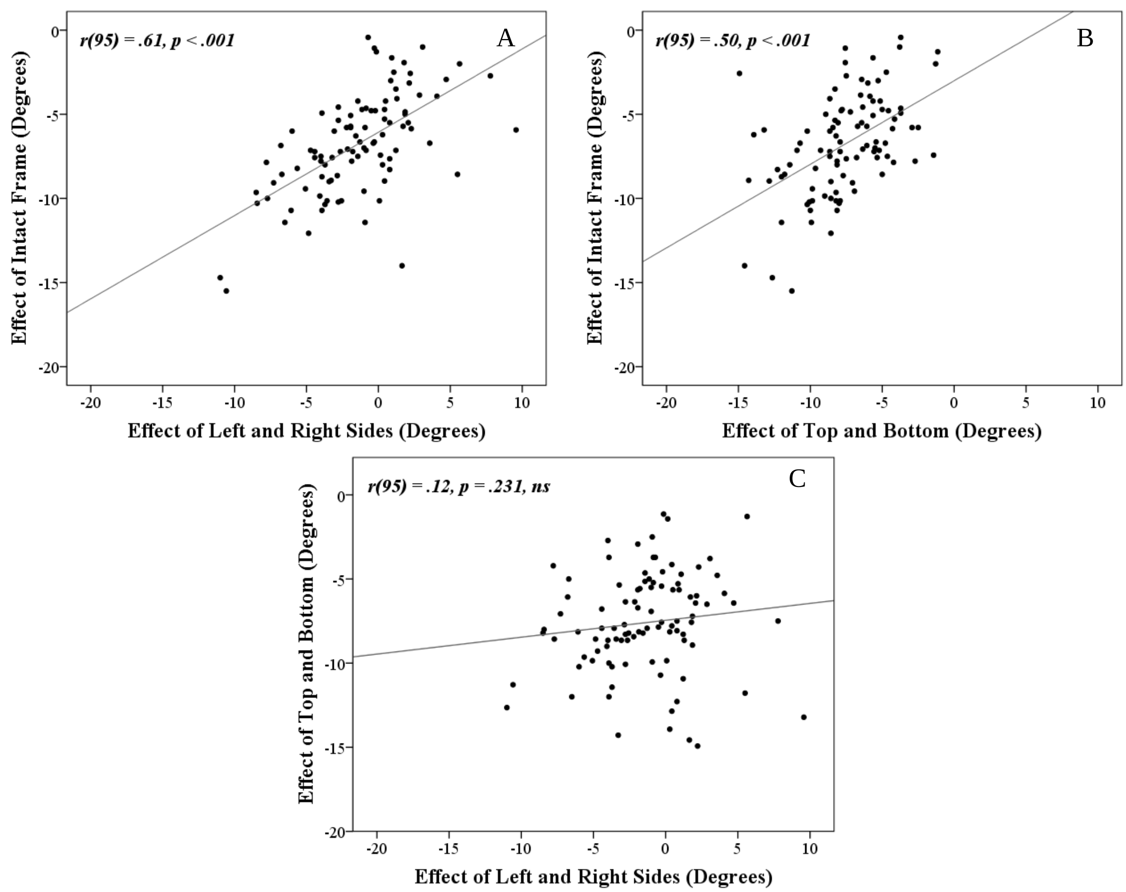

Figure 9: Correlations of Contextual Effects – Experiment 2

Pearson correlations between illusory contextual effects. (A, B) The effects of both component conditions were correlated to the intact frame effect. (C) However, the effects of the two component conditions were not correlated to each other.

Relationship between Sensitivity and Insistence on Sameness

As in Experiment 1, we predicted that those scoring high on the insistence on sameness (IS) factor of the SQ-R would be more sensitive in their orientation judgments. However, we found no such correlation, $r(95) = .05$, $p = .608$, ns. Because a potential relationship between IS and sensitivity may be non-linear (as we saw in Experiment 1), we performed an independent-samples t-test to compare the sensitivity of orientation judgments between the upper and lower quartiles of IS scores. This test showed no significant difference between groups, $t(49) = -0.43$, $p = .669$.

On the assumption that the insistence on sameness/symmetry & ordering factor of the principle components analysis of the AQ, SQ-R, and VOCI-R might provide a more sensitive measure of insistence on sameness tendencies, we also examined the relationship between this factor and the sensitivity measured in the perceptual task. However, there was no significant correlation between these measures, $r(95) = .05$, $p = .628$. An independent-samples t-test demonstrated that sensitivity of orientation judgments did not significantly differ between the upper and lower quartiles of the insistence on sameness/symmetry & ordering factor, $t(47) = 0.41$, $p = .683$, ns.

Relationship between Contextual Effects and Insistence on Sameness

We expected the left and right sides of the frame to cause a repulsive effect similar in magnitude to the 15 degree flankers in Experiment 1, which was correlated to the insistence on sameness factor of the SQ-R. Surprisingly, an independent-samples t-test showed that the effect of the left and right sides was significantly smaller than the effect of the 15 degree flankers in Experiment 1 (mean difference = -2.35), $t(204.89) = -4.05$, $p < .001$. It should also be noted that the effect of the intact frame from Experiment 2 was also significantly smaller than the effect of the intact frame from Experiment 1 (mean difference = -1.67), $t(202) = -3.90$, $p < .001$.

None of the contextual effects were correlated to the insistence on sameness factor of SQ-R or the insistence on sameness/symmetry & ordering factor of the principle components analysis of the current study (Table 5). Additionally, independent-samples t-tests showed no differences in contextual effects between the upper and lower quartiles of either of these measures (Table 6).

		IS	IS/S&O	Left/Right	Top/Bottom	Frame
IS	Pearson Correlation	1	.887***	-.027	-.129	-.052
	Sig. (2-tailed)		.000	.790	.209	.616
	N	103	103	97	97	97
IS/S&O	Pearson Correlation	.887***	1	.092	-.119	.000
	Sig. (2-tailed)	.000		.369	.245	.998
	N	103	103	97	97	97
Left/Right	Pearson Correlation	-.027	.092	1	.123	.606***
	Sig. (2-tailed)	.790	.369		.231	.000
	N	97	97	97	97	97
Top/Bottom	Pearson Correlation	-.129	-.119	.123	1	.497***
	Sig. (2-tailed)	.209	.245	.231		.000
	N	97	97	97	97	97
Frame	Pearson Correlation	-.052	.000	.606***	.497***	1
	Sig. (2-tailed)	.616	.998	.000	.000	
	N	97	97	97	97	97

Table 5: Correlations Between Contextual Effects, IS and IS/S&O – Experiment 2

Pearson correlations for illusory contextual effects against IS, IS/S&O and each other. The effects of both component conditions were correlated to the intact frame effect. However, the effects of the two component conditions were not correlated to each other. No significant correlations between contextual conditions and IS or IS/S&O were found. ****p* < .001.

	Mean Difference	df	*t*	*p*
***Insistence on Sameness (IS)*:**				
Left and Right Sides	-0.33	49.00	-0.36	.720
Top and Bottom	-1.04	49.00	-1.38	.174
Intact Frame	-0.42	49.00	-0.51	.613
***Insistence on Sameness/Symmetry & Ordering (IS/S&O)*:**				
Left and Right Sides	0.08	47.00	0.07	.942
Top and Bottom	-0.88	47.00	-1.21	.231
Intact Frame	0.19	47.00	0.22	.825

Table 6: Effect Differences for Upper/Lower Quartiles of IS and IS/S&O – Experiment 2

Independent-samples t-tests for differences in contextual effects between upper and lower quartiles of IS and IS/S&O. Mean difference = mean upper quartile effect – lower quartile effect. No significant differences were found, $p > .05$.

Discussion

Flanker Effects – Experiment 1

In Experiment 1, we investigated the relationship between the systemizing trait of autism and contextual effects thought to be driven by interactions of single-unit receptive fields in primary visual cortex (Kapadia et al., 2000). As hypothesized, we found that those with a high insistence on sameness were more sensitive in their orientation judgments, while also showing greater repulsive effects of lateral flankers. This finding supports past work, which demonstrated that those with high IS experienced greater orientation contrast effects with lateral flankers (Peterson et al., 2015).

At the neural level, these local contrast effects are thought to be elicited by mutually inhibitory connections within early visual processing (Poom, 2000). Populations of neurons in V1 – distributed in orientation columns – are linked by inhibitory interneurons. When one cell is activated, it reduces the firing rate of its neighbors through lateral inhibition. By averaging the differential firing rates of many neurons, the brain is able to accurately deduce the stimulus that is most likely present in the visual field. However, in so-called tilt illusions, contextual distractors outside of a neuron's classical receptive field can cause such lateral inhibition, incorrectly biasing the population code and causing a misperception of the orientation of a target stimulus (Clifford, 2014).

Indeed, with stimuli very similar to ours, Kapadia and colleagues (2000) found that, in the macaque, the presence of lateral flankers inhibited neurons encoding the tilt of the target line. In both monkeys and humans, their psychophysical data suggested that this inhibition resulted in a repulsive illusory effect. With thicker sensory cortices (Hyde et al., 2010) and atypical neural connectivity that skews white-matter microarchitecture toward local-tracts instead of global-tracts (Belmonte et al., 2004), those with autistic traits may experience more lateral inhibition between units in neighboring V1 orientation columns. This would lead to the pattern of flanker results found in Experiment 1, with high systemizers being more affected by the context but more precise in their orientation judgments.

The findings of the present study are also consistent with the Enhanced Perceptual Functioning theory of autism, which posits that enhanced flow of sensory information through early neural networks causes individuals with autism to have superior sensory discrimination (Mottron et al., 2006). Atypical low-level processing, as we observed here, would make it difficult for attention to control perceptual processes in individuals with autistic tendencies. In higher stages of visual processing, this abnormality could result in Weak Central Coherence (Happé & Frith, 2006). That is, individuals with autistic tendencies would have a local bias and often fail to integrate global information, providing immunity from some visuospatial illusions (Happé, 1996; Bölte et al., 2007).

Indeed, in the Rod-and-Frame illusion, Reed and Dassonville (2012) found that high systemizers relied less heavily on global cues and more heavily on local orientation cues (as seen in our flanker data from Experiment 1). Higher scores on the “analytical tendencies” factor of the SQ-R predicted decreased global effects, while higher scores on the insistence on sameness factor predicted increased local orientation contrast effects. These distinct perceptual mechanisms, while orthogonal, are likely comorbid in those with autistic traits.

Rod-and-Frame Effect – Experiments 1 and 2

Surprisingly, when the flankers in Experiment 1 were replaced with a small tilted frame, the repulsive effects were even larger, but they were uncorrelated with IS. In Experiment 2, we dissected the frame into its component parts, in an attempt to tease apart the specific features that drove the repulsive effect while not being correlated to IS.

The tilted frame is composed of lateral flankers tilted 15 degrees from vertical (i.e., the left and right sides), and collinear flankers tilted 75 degrees from vertical (i.e., the top and bottom). Given our findings in Experiment 1, we hypothesized in Experiment 2 that the left and right sides of the frame would cause a repulsive effect similar in magnitude to the lateral 15 degree flankers, and we expected that effect to be correlated to IS. Because the repulsive effect of the intact frame was uncorrelated with IS, we hypothesized that the repulsive effect of the frame's top and bottom must also be uncorrelated with IS, so as to overwhelm and obscure the IS correlation of the sides of the frame. However, we still expected IS to be correlated to sensitivity, with higher scores leading to improved orientation discrimination.

In Experiment 2, we actually discovered that the left and right sides of the frame induced an effect that was significantly smaller than that of the 15 degree flankers in Experiment 1. There are a couple of possible explanations for this finding. First and foremost, while these contextual stimuli were similar, they were not identical. The left and right sides of the frame were physically larger (32 minutes of visual angle) than the flankers (12 minutes of visual angle, which is the estimated size of an individual V1 receptive field; Kapadia et al., 2000). The left and right sides of the frame likely elicited a wider activation of neurons in V1. However, the connectivity of those neurons may have caused less contextual modulation in the units encoding the tilt of the target line, resulting in a smaller effect. This changed neural activation may also be why we did not see a significant correlation between IS and the effect of the left and right sides of the frame.

A second possibility is that the task modifications between Experiments 1 and 2 had some role in attenuating the effect. The fixation point in Experiment 1 was replaced with a vertical reference line in Experiment 2. This certainly led to a more stable perception of vertical and could have provided an induced motion cue when the reference line was replaced with the target line. Stimulus presentation times were slightly longer, and participants were required to take one minute breaks every 200 trials in Experiment 2. Our adaptive-staircase design also greatly reduced the number of trials required to assess sensitivity and the contextual effects of the stimuli. Any of these deviations in the task could have diminished the effect of the left and right sides. Given the fact that the intact frame – which was physically identical between Experiments 1 and 2 – also elicited a significantly smaller effect in Experiment 2 makes this seem probable. The correlation with IS could have disappeared simply because of decreased variability in performance of the task.

The top and bottom flankers caused a repulsive effect substantially larger than that of the left and right sides. However, the effects caused by the sides, and the top and bottom were both correlated with the overall effect of the intact frame (that is, participants with large flanker effects also tended to have large effects in the intact frame condition). This indicates that both flanker types played a role in driving the overall frame effect. Interestingly, however, the effect of the sides was not correlated with the effect of the top and bottom, indicating that these effects were driven by independent cellular mechanisms. Finally, the effect of the intact frame was significantly smaller than the mathematical sum of the separate effects of the sides and top and bottom, indicating that the overall effect of the frame was a weighted average of the two component conditions, both of which were uncorrelated to IS.

This underadditivity of orthogonal cellular mechanisms was not unexpected. Wenderoth and Beh (1977) found that the visuovestibular Rod-and-Frame effect could be induced by a stimulus consisting of only two lines, indicating that an intact frame was not necessary to achieve the illusion. Furthermore, Li and Matin (2005) demonstrated that the gestalt of an intact frame provided no additional impact to the illusion, as the visuovestibular effect of an intact frame was less than the sum of its parts. Here we found that the same was true of the local orientation contrast effects of the small-frame version of the Rod-and-Frame illusion.

It should be noted that the flanker effects in both experiments were strikingly different than those of Kapadia and colleagues (2000), who would have predicted an eight degree repulsive effect for lateral flankers tilted 15 degrees from vertical and virtually no effect for collinear flankers tilted 75 degrees from vertical. The major difference between the present study and that of Kapadia and colleagues (2000) was the sample size. The current study had close to 100 participants in each experiment, while

Kapadia and colleagues (2000) had only four. With increased statistical power, our effect sizes were likely more reliable.

Autism and OCD

In Experiment 2, we investigated the link between ASD, OCD, and the orientation contrast effects of the Rod-and-Frame illusion. Our principal components analysis showed one interesting factor of overlap (the insistence on sameness/symmetry & ordering factor), which was driven by the attention to detail and attention switching subscores of the AQ, the insistence on sameness factor of the SQ-R, and the symmetry and ordering subscore of the VOCI-R. This finding is in line with past work, which showed that, at the neuroanatomical level, ASD and OCD have been linked to an increased volume of the caudate nucleus of the basal ganglia. This increased volume likely leads to an atypically distributed neural network, which may underlie ritualistic-repetitive behaviors, unique motor mannerisms (tics), an insistence on sameness, and decremented hierarchical processing found in both disorders (Sears et al., 1999).

By using OCD measures to increase the number of items assessing tendencies associated with an insistence on sameness, we hoped to gain statistical power for our analyses of individual differences. However, in Experiment 2, we found that neither the IS component of SQ-R nor the IS/S&O factor of the current principle components analysis predicted orientation contrast effects. The same was true of the sensitivity of the orientation judgments. This lack of replication was surprising, but it may be attributed to stimulus and task differences. Namely, a decrease in perceptual variability could have eliminated any weak correlations, despite an increase in statistical power in the questionnaires.

Limitations

A limitation of the present study is that single unit responses were not directly recorded. Because of this, it is difficult to interpret our inconsistent results through the lens of inhibitory interactions. Past work has been inconclusive on the relationship between physiology and autism. Some claim that environmental and genetic factors may cause an imbalance of excitation and inhibition in ASD (Velázquez & Galán, 2013) while others have found no such relationship (Said, Egan, Minshew, Behrmann & Heeger, 2013). Measuring autistic and obsessive compulsive traits in the neurotypical population helps avoid sampling error inherent to clinical populations. However, investigating the relationship between insistence on sameness in an ASD or OCD sample would help elucidate potential links to perceptual differences. It is very possible that the effects we were investigating, while present, were very small and hence difficult to detect in a neurotypical population. This would leave our experiments susceptible to loss of power from stimulus and task changes (as observed between Experiments 1 and 2).

Future Directions

Given our inconclusive results, future research should further investigate the link between ASD, OCD, and the local orientation contrast effects of the Rod-and-Frame illusion. Manipulations of stimulus parameters, including corners, flanker length and angle, and target orientation, could provide further clues into the cellular mechanisms driving the orientation contrast effects of the Rod-and-Frame illusion, and how those potentially vary in ASD and OCD.

Conclusions

In summary, we found that individuals who scored high on the insistence on sameness component of systemizing were more sensitive in their orientation judgments, while also showing a greater repulsive effect of lateral flankers. However, when the flankers were replaced with a small tilted frame, the repulsive effects were even larger, but they were uncorrelated with insistence on sameness. Experiment 2 dissected the frame into its component parts in an attempt to tease apart the specific features that drove the repulsive effect while not being correlated to the systemizing trait of autism. Surprisingly, we discovered that the left and right sides of the frame induced a significantly smaller effect than lateral flankers of the same tilt. However, the top and bottom of the frame induced a large repulsive effect that even exceeded that of the frame. This pattern of results indicates that there is an underadditivity of orthogonal cellular mechanisms driving the orientation contrast effects of the Rod-and-Frame illusion, though neither of these effects (nor sensitivity) were correlated with ASD or OCD. Future work should further investigate this underadditivity, as well as the link between ASD, OCD, and local contrast effects. Such work may provide clues into the manner in which neural architecture differs between neurotypical individuals and those with autism.

Appendix

Autism Quotient (AQ; Baron-Cohen et al., 2001)

The AQ is made up of 50 questions, which can be divided into five categories: social skills, attention switching, attention to detail, communication, and imagination. Higher scores indicate greater autistic tendencies. While completing the AQ, participants indicated how much they agreed or disagreed with a statement on a four-point scale. Responses included “definitely agree,” “slightly agree,” “slightly disagree,” and “strongly disagree.” Both of the “agree” responses (or both of the “disagree” responses for statements that were reverse-coded) received one point.

	Item	Statement	Coding
Attention Switching			
	2	I prefer to do things the same way over and over again.	Forward
	4	I frequently get so strongly absorbed in one thing that I lose sight of other things.	Forward
	10	In a social group I can easily keep track of several different people's conversations.	Reverse
	16	I tend to have very strong interests which I get upset about if I can't pursue.	Forward
	25	It does not upset me if my daily routine is disturbed.	Reverse
	32	I find it easy to do more than one thing at once.	Reverse
	34	I enjoy doing things spontaneously.	Reverse
	37	If there is an interruption, I can switch back to what I was doing very quickly.	Reverse
	43	I like to plan any activities I participate in carefully.	Forward
	46	New situations make me anxious.	Forward
Attention to Detail			
	5	I often notice small sounds when others do not.	Forward
	6	I usually notice car number plates or similar strings of information.	Forward
	9	I am fascinated by dates.	Forward
	12	I tend to notice details that others do not.	Forward

	Item	Statement	Coding
	19	I am fascinated by numbers.	Forward
	23	I notice patterns in things all the time.	Forward
	28	I usually concentrate more on the whole picture, rather than the small details.	Reverse
	29	I am not very good at remembering phone numbers.	Reverse
	30	I don't usually notice small changes in a situation, or a person's appearance.	Reverse
	49	I am not very good at remembering people's date of birth.	Reverse
Communication			
	7	Other people frequently tell me that what I've said is impolite, even though I think it is polite.	Forward
	17	I enjoy social chit-chat.	Reverse
	18	When I talk, it isn't always easy for others to get a word in edgeways.	Forward
	26	I frequently find that I don't know how to keep a conversation going.	Forward
	27	I find it easy to "read between the lines" when someone is talking to me.	Reverse
	31	I know how to tell if someone listening to me is getting bored.	Reverse
	33	When I talk on the phone, I'm not sure when it's my turn to speak.	Forward
	35	I am often the last to understand the point of a joke.	Forward
	38	I am good at social chit-chat.	Reverse
	39	People often tell me that I keep going on and on about the same thing.	Forward
Imagination			
	3	If I try to imagine something, I find it very easy to create a picture in my mind.	Reverse
	8	When I'm reading a story, I can easily imagine what the characters might look like.	Reverse
	14	I find making up stories easy.	Reverse
	20	When I'm reading a story, I find it difficult to work out the characters' intensions.	Forward
	21	I don't particularly enjoy reading fiction.	Forward
	24	I would rather go to the theatre than a museum.	Reverse
	40	When I was young, I used to enjoy playing games involving pretending with other children.	Reverse
	41	I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.)	Forward

	Item	Statement	Coding
	42	I find it difficult to imagine what it would be like to be someone else.	Forward
	50	I find it very easy to play games with children that involve pretending.	Reverse
Social Skills			
	1	I prefer to do things with others rather than on my own.	Reverse
	11	I find social situations easy.	Reverse
	13	I would rather go to a library than a party.	Forward
	15	I find myself drawn more strongly to people than things.	Reverse
	22	I find it hard to make new friends.	Forward
	36	I find it easy to work out what someone is thinking or feeling just by looking at their face.	Reverse
	44	I enjoy social occasions.	Reverse
	45	I find it difficult to work out people's intentions.	Forward
	47	I enjoy meeting new people.	Reverse
	48	I am a good diplomat.	Reverse

Systemizing Quotient-Revised (SQ-R; Wheelwright et al., 2006)

The SQ-R has 75 questions, with higher scores again indicating greater autistic tendencies. While completing the SQ-R, participants again specified how much they agreed or disagreed with a statement on a four-point scale. As with the AQ, the responses included "definitely agree," "slightly agree," "slightly disagree," and "strongly disagree." Unlike the AQ, for the SQ-R (Wheelwright et al., 2006), the "slightly agree" and "definitely agree" responses (or the "slightly disagree" and "definitely disagree" responses for statements that were reverse-coded) received one and two points, respectively. Reed and Dassonville (2012) found that, based on the content of the questions, a subset of the items in the SQ-R can be categorized into two distinct factors, with an "insistence on sameness" factor comprising 12 questions and an "analytical tendencies" factor comprising 26 questions.

	Item	Statement	Coding
Analytical Tendencies			
	6	I find it difficult to read and understand maps.	Reverse
	7	When I look at a mountain, I think about how precisely it was formed.	Forward
	8	I am not interested in the details of exchange rates, interest rates, stocks and shares.	Reverse
	9	If I were buying a car, I would want to obtain specific information about its engine capacity.	Forward
	10	I find it difficult to learn how to program video recorders.	Reverse
	11	When I like something I like to collect a lot of different examples of that type of object, so I can see how they differ from each other.	Forward
	15	I find it difficult to understand instruction manuals for putting appliances together.	Reverse
	16	When I look at a building, I am curious about the precise way it was constructed.	Forward
	17	I am not interested in understanding how wireless communication works (e.g. mobile phones).	Reverse

	Item	Statement	Coding
	18	When travelling by train, I often wonder exactly how the rail networks are coordinated.	Forward
	25	I find it easy to grasp exactly how odds work in betting.	Forward
	26	I do not enjoy games that involve a high degree of strategy (e.g. chess, Risk, Games Workshop).	Reverse
	27	When I learn about a new category, I like to go into detail to understand the small differences between different members of that category.	Forward
	30	I can remember large amounts of information about a topic that interests me (e.g. flags of the world, airline logos).	Forward
	32	I am fascinated by how machines work.	Forward
	34	I know very little about the different stages of the legislation process in my country.	Reverse
	35	I do not tend to watch science documentaries on television or read articles about science and nature.	Reverse
	40	I am not interested in how the government is organized into different ministries and Departments.	Reverse
	41	I am interested in knowing the path a river takes from its source to the sea.	Forward
	45	I rarely read articles or webpages about new technology.	Reverse
	46	I can easily visualize how the motorways in my region link up.	Forward
	50	When I am walking in the country, I am curious about how the various kinds of trees differ.	Forward
	53	If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed.	Forward
	60	If I were buying a stereo, I would want to know about its precise technical features.	Forward
	70	When I'm in a plane, I do not think about the aerodynamics.	Reverse
	74	When I listen to a piece of music, I always notice the way it's structured.	Forward
Insistence on Sameness			
	2	I like music or book shops because they are clearly organized.	Forward
	14	If I had a collection (e.g. CD's, coins, stamps), it would be highly organized.	Forward
	20	Whenever I run out of something at home, I always add it to a shopping list.	Forward

	Item	Statement	Coding
	21	I know, with reasonable accuracy, how much money has come in and gone out of my bank account this month.	Forward
	28	I do not find it distressing if people who live with me upset my routines.	Reverse
	31	At home, I do not carefully file all important documents (e.g. guarantees, insurance policies).	Reverse
	44	My clothes are not carefully organized into different types in my wardrobe.	Reverse
	55	When I get to the checkout at a supermarket, I pack different categories of goods into separate bags.	Forward
	56	I do not follow any particular system when I'm cleaning at home.	Reverse
	65	It does not bother me if things in the house are not in their proper place.	Reverse
	71	I do not keep careful records of my household bills.	Reverse
	72	When I have a lot of shopping to do, I like to plan which shops I am going to visit and in what order.	Forward
SQ-R			
	1	I find it very easy to use train timetables, even if this involves several connections.	Forward
	3	I would not enjoy organizing events (e.g. fundraising evenings, fetes, conferences).	Reverse
	4	When I read something, I always notice whether it is grammatically correct.	Forward
	5	I find myself categorizing people into types (in my own mind).	Forward
	12	When I learn a language, I become intrigued by its grammatical rules.	Forward
	13	I like to know how committees are structured in terms of who the different committee members represent or what their functions are.	Forward
	19	I enjoy looking through catalogs of products to see the details of each product and how it compares to others.	Forward
	22	When I was young, I did not enjoy collecting sets of things (e.g. stickers, football cards, etc.)	Reverse
	23	I am interested in my family tree and in understanding how everyone is related to each other in the family.	Forward
	24	When I learn about historical events, I do not focus on exact dates.	Reverse

	Item	Statement	Coding
	29	When I look at an animal, I like to know the precise species it belongs to.	Forward
	33	When I look at a piece of furniture, I do not notice the details of how it was constructed.	Reverse
	36	If someone stops to ask me the way, I'd be able to give directions to any part of my home town.	Forward
	37	When I look at a painting, I do not usually think about the technique involved in making it.	Reverse
	38	I prefer social interactions that are structured around a clear activity (e.g. a hobby).	Forward
	39	I do not always check off receipts etc. against my bank statement.	Reverse
	42	I have a large collection (e.g. of books, CDs, videos, etc.).	Forward
	43	If there was a problem with the electrical wiring in my home, I'd be able to fix it.	Forward
	47	When an election is being held, I am not interested in the results for each constituency.	Reverse
	48	I do not particularly enjoy learning about facts and figures in history.	Reverse
	49	I do not tend to remember people's birthdays (in terms of which day and month this falls).	Reverse
	51	I find it difficult to understand information the bank sends me on different investment and savings systems.	Reverse
	52	If I were buying a camera, I would not look carefully into the quality of the lens.	Reverse
	54	I do not read legal documents very carefully.	Reverse
	57	I do not enjoy in-depth political discussions.	Reverse
	58	I am not very meticulous when I carry out D.I.Y or home improvements.	Reverse
	59	I would not enjoy planning a business from scratch to completion.	Reverse
	61	I tend to keep things that other people might throw away, in case they might be useful for something in the future.	Forward
	62	I avoid situations which I cannot control.	Forward
	63	I do not care to know the names of the plants I see.	Reverse
	64	When I hear the weather forecast, I am not very interested in the meteorological patterns.	Reverse
	66	In maths, I am intrigued by the rules and patterns governing numbers.	Forward
	67	I find it difficult to learn my way around a new city.	Reverse

	Item	Statement	Coding
	68	I could list my favorite 10 books, recalling titles and authors' names from memory.	Forward
	69	When I read the newspaper, I am drawn to tables of information, such as football league scores or stock market indices.	Forward
	73	When I cook, I do not think about exactly how different methods and ingredients contribute to the final product.	Reverse
	75	I could generate a list of my favorite 10 songs from memory, including the title and the artist's name who performed each song.	Forward

Vancouver Obsessional Compulsive Inventory (VOCI; Thordarson et al., 2004)

While completing the VOCI, participants indicated how accurately a statement described themselves on a five-point scale. Responses included "not at all," "a little," "some," "much," and "very much." These responses received zero to four points, respectively. Higher scores indicated greater obsessive-compulsive tendencies. The VOCI has 55 questions, which can be divided into six categories: checking, contamination, hoarding, indecisiveness, just right, and obsessions.

	Item	Statement
Checking		
	7	I repeatedly check and recheck things like taps and switches after turning them off.
	20	I repeatedly check that my doors or windows are locked, even though I try to resist the urge to do so.
	33	One of my major problems is repeated checking.
	37	I repeatedly check that my stove is turned off, even though I resist the urge to do so.
	41	I spend a lot of time every day checking things over and over again.
	43	I frequently have to check things like switches, faucets, appliances, and doors several times.
Contamination		
	3	I feel very dirty after touching money.
	8	I use an excessive amount of disinfectants to keep my home or myself safe from germs.
	13	I spend far too much time washing my hands.
	15	Touching the bottom of my shoes makes me very anxious.
	21	I find it very difficult to touch garbage or garbage bins.
	23	I am excessively concerned about germs and disease.
	25	I avoid using public telephones because of possible contamination.
	32	I feel very contaminated after I touch an animal.
	39	I am very afraid of having even slight contact with bodily secretions (blood, urine, sweat, etc.).
	44	One of my major problems is that I am excessively concerned about cleanliness.
	49	I often experience upsetting and unwanted thoughts about illness.
	50	I am afraid to use even well kept public toilets because I am so concerned about germs.

	Item	Statement
Hoarding		
	10	I have trouble carrying out normal household activities because my home is so cluttered with things I have collected.
	22	I become very tense or upset when I think about throwing anything away.
	26	I am embarrassed to invite people to my home because it is full of piles of worthless things I have saved.
	35	I find it almost impossible to decide what to keep and what to throw away.
	42	I have great trouble throwing anything away because I am very afraid of being wasteful.
	45	I feel compelled to keep far too many things like old magazines, newspapers, and receipts because I am afraid I might need them in the future.
	51	Although I try to resist, I feel compelled to collect a large quantity of things I never actually use.
Indecisiveness		
	4	I find it very difficult to make even trivial decisions.
	11	After I have decided something, I usually worry about my decision for a long time.
	17	I become very anxious when I have to make even a minor decision.
	29	I worry far too much that I might upset other people.
	31	I almost always count when doing a routine task.
	48	I try to put off making decisions because I'm so afraid of making a mistake.
Just Right		
	1	I feel compelled to check letters over and over before mailing them.
	5	I feel compelled to be absolutely perfect.
	9	I often feel compelled to memorize trivial things (e.g., license plate numbers, instructions on labels).
	14	I often have trouble getting things done because I try to do everything exactly right.
	18	I feel compelled to follow a very strict routine when doing ordinary things.
	19	I feel upset if my furniture or other possessions are not always in exactly the same position.
	24	I am often very late because I can't get through ordinary tasks on time.
	36	I am strongly compelled to count things.
	38	I get very upset if I can't complete my bedtime routine in exactly the same way every night.
	47	I tend to get behind in my work because I repeat the same thing over and over again.

	Item	Statement
	53	One of my major problems is that I pay far too much attention to detail.
	55	I spend far too long getting ready to leave home each day because I have to do everything exactly right.
Obsessions		
	2	I am often upset by my unwanted thoughts of using a sharp weapon.
	6	I repeatedly experience the same unwanted thought or image about an accident.
	12	I find that almost every day I am upset by unpleasant thoughts that come into my mind against my will.
	16	I am often upset by my unwanted thoughts or images of sexual acts.
	27	I repeatedly experience the same upsetting thought or image about death.
	28	I am often upset by unwanted thoughts or images of blurting out obscenities or insults in public.
	30	I am often frightened by unwanted urges to drive or run into oncoming traffic.
	34	I often experience upsetting and unwanted thoughts about losing control.
	40	I am often very upset by my unwanted impulses to harm other people.
	46	I repeatedly experience upsetting and unacceptable thoughts of a religious nature.
	52	I repeatedly experience upsetting and unwanted immoral thoughts.
	54	I am often upset by unwanted urges to harm myself.

Symmetry, Ordering and Arranging Questionnaire (SOAQ; Radmosky & Rachman, 2004)

While completing the SOAQ, participants again indicated how true each statement was of them on a five-point scale. As with the VOCI, responses on the SOAQ included “not at all,” “a little,” “some,” “much,” and “very much,” and these responses received zero to four points, respectively. The SOAQ has twenty questions, with higher scores again indicating greater obsessive-compulsive tendencies.

Item	Statement
1	I feel upset if my furniture is not always in exactly the same position.
2	Other people think I spend too much time ordering and arranging my belongings.
3	It is essential that I arrange my clothing in a particular and specific way.
4	I am more at ease when my belongings are “just right.”
5	I must keep my papers, receipts, documents, etc. organized according to a specific set of rules.
6	It is important that my belongings are placed in a symmetrical and evenly distributed way.
7	If someone accidentally disturbs my belongings – however slightly, I become bothered or upset.
8	I feel compelled to arrange my possessions until it feels “just right.”
9	When I think that my belongings are out of place, I am uncomfortable or anxious.
10	When I put things away, I feel compelled to do it carefully and precisely.
11	The furniture in my home must be in exactly the “right” spot.
12	I feel calm and relaxed only when objects around me are organized and placed correctly.
13	I feel compelled to arrange cans or boxes of food on my kitchen shelves in a specific way.
14	When I see that my belongings are out of place, I become anxious until I can arrange them properly.
15	I feel compelled to arrange objects so that they are balanced and evenly spaced.
16	I feel calm/at ease only when my surroundings are neat and tidy.
17	Even when my home is messy, I keep things organized according to a specific set of rules.
18	Things in my home have a proper and exact place.
19	I cannot concentrate unless things are in the right place.
20	I don’t like to disturb objects once they are properly arranged.

Vancouver Obsessional Compulsive Inventory-Revised (VOCI-R; Gonner et al., 2010)

From a subset of items on the VOCI and the SOAQ, we were able to derive scores on the VOCI-R, which uses the same scoring system. We also calculated the five sub-scores of the VOCI-R: checking, contamination, hoarding, obsessions, and symmetry and ordering. The obsessions subscore is further divided into the harming and immoral categories. For every subscore except symmetry and ordering, the item number refers to the statement in the VOCI.

	Item	Statement
Checking		
	7	I repeatedly check and recheck things like taps and switches after turning them off.
	20	I repeatedly check that my doors or windows are locked, even though I try to resist the urge to do so.
	33	One of my major problems is repeated checking.
	37	I repeatedly check that my stove is turned off, even though I resist the urge to do so.
	41	I spend a lot of time every day checking things over and over again.
	43	I frequently have to check things like switches, faucets, appliances, and doors several times.
Contamination		
	13	I spend far too much time washing my hands.
	15	Touching the bottom of my shoes makes me very anxious.
	21	I find it very difficult to touch garbage or garbage bins.
	25	I avoid using public telephones because of possible contamination.
	39	I am very afraid of having even slight contact with bodily secretions (blood, urine, sweat, etc.).
	50	I am afraid to use even well kept public toilets because I am so concerned about germs.
Hoarding		
	10	I have trouble carrying out normal household activities because my home is so cluttered with things I have collected.

	Item	Statement
	22	I become very tense or upset when I think about throwing anything away.
	35	I find it almost impossible to decide what to keep and what to throw away.
	42	I have great trouble throwing anything away because I am very afraid of being wasteful.
	45	I feel compelled to keep far too many things like old magazines, newspapers, and receipts because I am afraid I might need them in the future.
	51	Although I try to resist, I feel compelled to collect a large quantity of things I never actually use.
Obsessions - Harming		
	2	I am often upset by my unwanted thoughts of using a sharp weapon.
	30	I am often frightened by unwanted urges to drive or run into oncoming traffic.
	40	I am often very upset by my unwanted impulses to harm other people.
Obsessions - Immoral		
	16	I am often upset by my unwanted thoughts or images of sexual acts.
	46	I repeatedly experience upsetting and unacceptable thoughts of a religious nature.
	52	I repeatedly experience upsetting and unwanted immoral thoughts.
Symmetry and Ordering		
	1	I feel upset if my furniture is not always in exactly the same position.
	7	If someone accidentally disturbs my belongings – however slightly, I become bothered or upset.
	12	I feel calm and relaxed only when objects around me are organized and placed correctly.
	14	When I see that my belongings are out of place, I become anxious until I can arrange them properly.
	15	I feel compelled to arrange objects so that they are balanced and evenly spaced.
	19	I cannot concentrate unless things are in the right place.

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